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INTRODUCTION

Calibrated strain gages have been extensively used to measure aircraft loads in flight, particularly on lifting surfaces. The prevailing calibration method (ref. 1) is based on the approach that although the stress in structural members may not be a simple, direct function of shear, bending moment, or torque it is possible to combine the responses of selected strain gages to provide a measure of each parameter. This method, which was first used on aircraft in the 1940's, has clearly withstood the tests of time. However, the method has most universally been used on high aspect ratio structures, where load paths from the wing to the fuselage are few, well defined, and minimally redundant. Aircraft designed for high speed flight are characterized by lower aspect ratio structures with highly redundant, multispar configurations. As shown in references 2 to 8 such configurations considerably complicate the task of measuring flight loads with strain gages, because the pertinence of any given load equation becomes more difficult to assess.

The approach usually taken with low aspect ratio, multispar structures is to instrument the structure extensively with strain gages to insure that no crucial load paths are missed. Consequently, a large array of strain sensors is available for use in the load equations. One approach for selecting the strain gages to be used in the load equations is referred to as the T-value method (refs. 2 to 4).

A special adaptation of the T-value method is introduced in this paper. The adaptation involves the incorporation of three additional parameters in the process used to determine the value of each strain gage bridge to the load equation. The new adaptation, called the modified T-value method, is assessed by comparing the load-measuring capabilities of the two methods. The methods are compared by examining the deviation of the calculated load from the applied load for the two methods.

The computer program used to implement the modified T-value method is described in the appendix, which was written by Donald C. Black.

SYMBOLS

The physical quantities in this report are given in both the International System of Units (SI) and U. S. Customary Units. Measurements were made in Customary Units. Physical constants and conversion factors are given in reference 5.

BA	bending arm (fig. 11)
b	wingspan, m (in.)
c	wing chord, m (in.)
L	generalized load; shear, bending moment, or torque
MT	modified T-value
T	T-value
TA	torque arm (fig. 11)
X	axis in chord direction
Y	axis in span direction
β	constant in load equation
γ	correlation coefficient between strain bridge response with all other strain gage bridge responses due to calibration loads
ε	standard error of constant β in load equation
μ	nondimensional strain gage bridge response
$\bar{\mu}$	mean absolute magnitude of the nondimensional strain gage bridge response due to calibration loads
λ	correlation coefficient between the strain gage bridge response and the calibration loads

Subscripts:

1, 2, 3, . . ., j	order of terms' appearance in load equation
i	discrete function

TEST STRUCTURE

Results from a large number of hypersonic cruise aircraft studies (including refs. 6 to 8) led to the design and construction of the hypersonic wing test structure shown in figures 1 and 2. The test structure represents the primary wing box of a multispar low aspect ratio wing typical of hypersonic (Mach 8) flight. The test structure is primarily constructed of René 41 and has a planform area of 7.9 square meters (85 square feet). The six spars are spaced 50.8 centimeters (20 inches) apart and are covered by spanwise-stiffened beaded panels and chordwise-stiffened beaded heat shields. A more complete description of the hypersonic wing test structure is given in references 8 and 9.

INSTRUMENTATION

The load measurement instrumentation consisted of 12 four-active-arm strain gage bridges. The general locations of the strain gage bridges and the load points are shown in figure 3.

A bending bridge was installed on the cap of each of the six spars, and a shear bridge was installed on each of the respective spar webs. Typical installations of each type are shown in figures 4(a) and 4(b).

MEASUREMENT ACCURACY

The strain gage bridges were calibrated for measuring shear, bending moment, and torque by the point-by-point procedure described in reference 1. Tension loads of 8896 newtons (2000 pounds) were applied at each of the 18 load points on the hypersonic wing test structure shown in figure 3.

The accuracy of the data acquisition system for strain gage measurements was estimated to be ±4.88 microstrain, which represents 0.3 percent of the strain gage calibrate output. A more complete description of the loading tests is given in reference 9.

DATA REDUCTION

Load Equations

The multiple linear square regression method described in references 1, 10, and 11 was used to derive shear, bending moment, and torque equations for measuring loads on the test structure. First all 12 strain gage bridges were used to relate the applied calibration loads to the bridge responses. The resulting generalized load equation is as follows:

$$L = \sum_{i=1}^{i=j} \mu_i \beta_i \tag{1}$$

where L is the applied load, μ is the nondimensional strain gage bridge response, and β is the load equation constant. A detailed analysis of the load calibration is given in reference 12.

T-Value Method

One method for reducing the number of terms in equation (1) is to use a value known as a T-value as a measure of the relevance of the bridge. References 2 and 4 define T-value as follows:

$$T_i = \frac{\beta_i}{\varepsilon_i} \tag{2}$$

where T_i is the T-value that indicates the relevance of the ith strain gage bridge, β_i is the equation constant, and ε_i is the standard error of the associated equation constant.

The number of bridges in the load equation can be successively reduced by eliminating the bridge with the smallest T-value. Each time a bridge is eliminated a new equation is derived from the remaining bridges and new T-values are calculated. For purposes of comparison with the modified method proposed in this paper, the procedure was repeated until a set of equations containing 12 to 2 strain gage bridges was derived. The resulting equation constants for measuring shear, bending moment, and torque are given in table 1.

Modified T-Value Method

The modified T-value method includes strain gage response magnitude, gage-to-load correlation, and gage-to-gage intercorrelation factors in the process of selecting the appropriate gages for the load equations. The modified T-values, or MT-values, are defined as follows:

$$MT_i = \frac{\bar{\mu}_i \lambda_i \beta_i}{\gamma_i \varepsilon_i} \tag{3}$$

where MT_i indicates the relevance of the ith strain gage bridge, $\bar{\mu}_i$ is the mean absolute magnitude of the nondimensional strain gage bridge response due to the calibration load, λ_i is the coefficient of correlation between the strain gage bridge response and the calibration load, β_i is the load equation constant, γ_i is the coefficient of correlation between the strain gage bridge response and all the other bridge responses due to the calibration load, and ε_i is the standard error of the load equation constant.

The MT-value method refines the selection of the strain gages by incorporating the $\bar{\mu}$, λ, and γ terms in equation (3).

The absolute magnitude of the gage response, $\bar{\mu}$, is important because the use of a gage with a large value of $\bar{\mu}$ in the load equation will cause the resolution error of the reading to be less significant than it would be with a gage with a small value of $\bar{\mu}$.

On a multisparred structure with redundant load paths like the hypersonic wing test structure (fig. 1), a strain gage bridge may be highly responsive to a load on the spar to which the gage is attached but not to a load on a more remote spar. The gage-to-load correlation coefficient, λ, is introduced in the MT-value method for this reason. A large value of λ indicates that the gage is sensitive to most of the applied calibration loads and thus should be retained in the load equation.

The size of the gage-to-gage correlation coefficient, γ, reflects the redundancy of a gage with respect to the remaining gages in the load equation. A small value of γ is desirable, for it indicates that a gage is unique in measuring a load.

The terms β, ε, $\bar{\mu}$, and λ are calculated as part of the statistical information that is generated in the multiple linear regression computer program used to derive the load equation constants (see appendix). The gage-to-gage correlation coefficient γ is calculated from a gage intercorrelation matrix also generated by the computer program. The method used to reduce the gage intercorrelation matrix to the correlation coefficient γ is described in reference 13.

In the MT method the number of gages in the load equation is reduced in the same manner as in the T-value method described in the previous section. The resulting shear, bending moment, and torque equation constants are given in table 2.

STRAIN GAGE BRIDGE INFLUENCE COEFFICIENTS

Influence coefficient plots which show the responses of individual strain gages as a function of the spanwise and chordwise location of a unit load are useful in assessing the effectiveness of a bridge for purposes of measuring shear, bending moment, and torque. The ideal responses are illustrated in reference 14.

The influence coefficients of the 12 strain gage bridges are shown in figures 5(a) and 5(b). All six bending bridges (fig. 5(a)) respond not only to bending but also to torque, as evidenced by the vertical spread of the data at any given span location. Similarly, all six shear bridges (fig. 5(b)) respond not only to shear but also to bending and torque. Hence, in order to measure shear, bending moment, and torque, combinations of a number of strain gage bridges are required.

LOAD EQUATION INFLUENCE COEFFICIENTS

Influence coefficient plots of complete load equations, computed by the method used in reference 15, illustrate the nature of the equations.

An ideal shear equation influence coefficient plot would appear as a line of zero slope. The lack of response to spanwise variation would indicate no sensitivity to bending, and at any given span location a lack of variation with changing chord location would indicate insensitivity to torque. Similarly, the ideal bending moment equation plot would be a straight line. And finally, the ideal torque equation plot would assume the planform of the load points. Figures 6, 7, and 8 show influence coefficient plots for the shear, bending moment, and torque equations derived by eliminating bridges with both the T and the MT methods. In general, the deviation of the equation influence coefficient plots from the ideal pattern increases as the number of bridges in the equation decreases from 12 to 2.

PERFORMANCE OF LOAD EQUATIONS

Since the purpose of a load equation is to calculate flight loads, the performance of the equations generated by the T and MT methods was evaluated using load distributions that were independent of the point-by-point calibration loads.

The three load distributions shown in figure 9 represent the aerodynamic loads on a wing during subsonic, supersonic, and maneuvering flight. (The reasons for believing the loads were representative of these flight conditions are given in reference 14.)

Figure 10(a) shows the comparison between the values computed for shear with the T and MT methods for the three load distributions. Reducing the number of bridges from 12 to 2 causes the computed shear to deviate from the applied load for both sets of equations. However, the shear values computed with the MT method are accurate more consistently than those computed with the T method. The improvement in the measurement is most obvious in the equations that contain six bridges or fewer. Figure 10(b) compares the performance of the T and MT methods in computing bending moment. The same trend exists in bending as for shear; again, the improvement in accuracy is greatest for equations containing six bridges or fewer.

The performance of the T and MT methods in computing torque is shown in figure 10(c). Again, the performance of the MT method is better. The improvement is greatest for equations containing five bridges or fewer. However, caution must be exercised when examining torque data because the quantities are dependent on the location of the torque reference axis.

A complete tabulation of the percentage of difference between the computed and applied shear, bending moment, and torque for the T and MT methods is given in table 3.

CONCLUDING REMARKS

A new adaptation of the previously used T-value method for selecting and determining the relevance of strain gages for measurement was applied to a multispar structure. The effect of the new approach, called the modified T-value method, was illustrated by reducing the number of strain gages used in a load equation from 12 to 2. The previously developed and modified methods were compared by calculating loads from three applied load distributions. The modified T-value method proved to be accurate more consistently than the T-value method.

Both the T-value method and the modified T-value method provide additional systematic, formalized approaches to selecting strain gages for use in load equations from the large array of gages typically found on multispar structures. The success of the modified T-value method on this structure suggests that the approach should be of value to engineers engaged in flight load measurement using strain gages.

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Edwards, California, January 8, 1980

APPENDIX—A COMPUTER PROGRAM FOR DERIVING LOAD EQUATION COEFFICIENTS USING REGRESSION TECHNIQUES

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This appendix describes the results of a computer program which derives load equation coefficients using regression techniques. The program was adapted to implement the MT method theory. The program, which is known as the EQDE (equation derivation) program, is run on a CDC Cyber computer and performs two primary functions. First, it calculates strain gage influence coefficients for each load condition selected by the user. An influence coefficient is the slope of the linear least-squares fit of strain versus load data. Second, the program derives, using a multiple linear regression technique, equation coefficients from independent variables (strains) and a dependent variable (load). In calculating the coefficients, related statistical analyses are performed, and the results are printed to assist the user in selecting the appropriate gages for the load equation.

The EQDE program can operate from either of two data sources. The first is a flight loads research laboratory engineering units data tape. The second is a user-created permanent data set which can contain as many as 2000 parameters per file (a file normally representing one time segment). In executing any single job, the program can handle as many as 50 strain gages (40 of which may be included in a single equation) and 50 load conditions. Each load condition must be defined by at least three data points.

In addition to calculating influence and equation coefficients, the EQDE program performs various mathematical analyses to aid the user in selecting the appropriate gages for load equations. User interpretation of this analysis is relative to the load conditions selected for analysis. If particular equations appear more appropriate than others, then they are so for the range of the load applied and the gage locations in the load conditions selected. The program does not try to predict the suitability of an equation for flight loads outside the specified range of load conditions. However, the more suitable an equation for the load conditions selected, the more likely it is that it will predict loads outside the specified load conditions range.

The terminology used in the EQDE program, which is described in more detail below, is defined in figure 11. A load point is determined by a user-prescribed bending arm (BA) and torque arm (TA). The bending arm is the shortest distance from the bending axis to the load point, while the torque arm is the shortest distance from the torque axis to the load point.

A load condition (a physical load that generates strain and load data) is defined by the amount of loading at one or more points on the structure. In a load condition that involves more than one load point, the mean bending arm is the shortest distance from the bending axis to the center of pressure of the applied loads. The mean torque arm is the shortest distance from the torque axis to the center of pressure of the applied loads.

The EQDE program operates in the following manner:

1. All control data cards are read, stored on disc, and printed. A cursory check is performed for correct format and sequence. The control data cards are reread up through the data set identification card, and the validity of the parameters and parameter values is checked.

2. A listing is created showing the processing statistics for the current job execution.

3. For each load condition, a load condition card and load cell cards are read, and the corresponding data from tape (or disc) are read. These data are saved after bending moment and torque values are computed (or read from the disc). Any data with shear values less than 10 percent of the maximum shear, or less than a user-supplied value, are deleted.

4. As each load condition is processed, the summations of the gage outputs and the gage cross products are updated. The mean bending and torque arms, along with their standard deviations, are computed for each load condition. After each load condition is processed, the strain gage influence coefficients, correlation coefficients, and influence coefficient standard errors are calculated and printed.

5. For all the data saved, the sum of the cross products of the standard deviations, the mean strain gage and load values (along with the standard deviations of these), and the gage correlation coefficients are calculated. A table that contains the intercorrelation values for all the gages selected is then printed.

6. After all load conditions have been processed, a table is printed that contains a listing of strain gage influence coefficients, mean bending arms, and mean torque arms for all load conditions.

7. Load equation definition and equation strain gage identification cards are read. The validity of the parameters for the user-defined equation is checked, and a subcase matrix is formed by combining the appropriate dependent and independent intercorrelations. This matrix is inverted, and if it is singular, an appropriate error message is printed and the program halts.

8. Beta weights, coefficients of determination, regression coefficients, multiple correlation coefficients, equation intercepts, and standard errors of the estimate (equation) are computed. Results of this multiple linear regression and strain/load data analysis are printed.

9. A table of residuals is calculated based on the estimate found by using derived coefficients and the originally applied load. The root mean square (rms) error of the estimate is divided by the rms of the load, and the result is printed.

10. Steps 7 to 9 are repeated for each equation defined by the user.

The EQDE program provides the user with many types of information that facilitate the selection of the appropriate strain gages. The following discussion details some of the more important mathematical features of the program.

1. A table of residuals shows the standard deviations of the bending arm and torque arm data sets, the strain and load data sets, and the estimate versus applied error data set. These calculations provide the user with an indication of the spread of the data around the mean of the data set.

2. As indicated above, the program computes strain gage influence coefficients and equation coefficients.

3. Correlations are computed for (1) gage output versus load for each load condition, (2) gage output versus gage output for all load conditions, and (3) gage output versus load for all selected load conditions. These correlations permit the user to compare the linearity of various parameters.

4. To permit the accuracy of a load equation for a given load condition to be evaluated, the standard error and then a table of residuals are computed for each load equation. The table of residuals (errors) can be in either of two formats. The first is the mean error (estimate minus actual load), together with the standard deviation of the mean error, for each load condition. The second is the residual (error) for each data point in the selected load condition.

5. An rms value is computed for (1) the (equation estimate minus applied load) error value and (2) the applied load for all load conditions. The values of (1) divided by (2) are then used to access the relative accuracy of the equation estimate in predicting applied loads.

A sample printout of the EQDE program is presented as table 4. The items numbered in the printout are explained at the end of the listing.

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TABLE 1.—LOAD EQUATION CONSTANTS DERIVED WITH T METHOD

(a) Constants for measuring shear. SI Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Shear, N/μ										
104	12.23	11.79	18.28	28.51	30.87	64.23	47.77	37.98	47.82	71.43	87.14
105	32.96	33.18	32.29	29.89	27.67	-----	-----	-----	-----	-----	-----
304	13.88	18.90	-----	-----	-----	-----	-----	-----	-----	-----	-----
305	31.00	29.89	33.72	36.38	37.58	22.28	72.15	91.45	64.72	-----	-----
504	12.10	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
505	33.72	36.12	34.83	31.98	31.40	11.08	-40.52	-41.94	46.35	87.85	-----
704	18.24	23.22	34.43	-----	-----	-----	-----	-----	-----	-----	-----
705	32.34	30.56	27.93	36.65	35.90	54.44	141.18	96.25	-----	-----	-----
904	18.15	20.28	20.10	43.32	-----	-----	-----	-----	-----	-----	-----
905	29.09	28.82	29.71	23.75	35.05	52.93	-59.25	-----	-----	-----	-----
1104	15.74	15.48	15.88	9.16	34.12	62.36	-----	-----	-----	-----	-----
1105	30.16	30.34	30.11	30.78	20.64	-11.39	78.64	61.87	75.44	78.28	87.58

(a) Constants for measuring shear. U. S. Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Shear, lb/μ										
104	2.75	2.65	4.11	6.41	16.94	14.44	10.74	8.54	10.75	16.06	19.59
105	7.41	7.46	7.26	6.72	6.22	-----	-----	-----	-----	-----	-----
304	3.12	4.25	----	----	-----	-----	-----	-----	-----	-----	-----
305	6.97	6.72	7.58	8.18	8.45	5.01	16.22	20.56	14.55	-----	-----
504	2.72	----	----	----	-----	-----	-----	-----	-----	-----	-----
505	7.58	8.12	7.83	7.19	7.06	2.49	-9.11	-9.43	10.42	19.75	-----
704	4.10	5.22	7.74	----	-----	-----	-----	-----	-----	-----	-----
705	7.27	6.87	6.28	8.24	8.07	12.24	31.74	21.64	-----	-----	-----
904	4.08	4.56	4.52	9.74	-----	-----	-----	-----	-----	-----	-----
905	6.54	6.48	6.68	5.34	7.88	11.90	-13.37	-----	-----	-----	-----
1104	3.54	3.48	3.57	2.06	7.67	14.02	-----	-----	-----	-----	-----
1105	6.78	6.82	6.77	6.92	4.64	-2.56	17.68	13.91	16.96	17.60	19.69

TABLE 1.—Continued

(b) Constants for measuring bending moment. SI Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Bending moment, m-N/μ										
104	47.19	45.32	56.89	59.05	57.66	56.37	77.24	78.96	79.91	125.08	139.54
105	-8.66	-7.11	-15.11	-19.14	------	------	------	------	------	------	------
304	63.43	71.33	45.91	68.06	36.97	55.44	------	------	------	------	------
305	-10.44	-16.98	------	------	------	------	------	------	------	------	------
504	59.16	48.50	43.10	45.90	46.11	------	------	------	------	------	------
505	-10.39	------	------	------	------	------	------	------	------	------	------
704	86.30	90.58	107.22	61.57	88.60	105.54	133.74	127.18	158.76	------	------
705	-15.52	-21.68	-32.59	------	------	------	------	------	------	------	------
904	95.08	96.18	96.09	119.34	140.91	150.59	151.84	46.76	69.02	193.21	------
905	-24.93	-24.29	-21.32	-49.50	-58.37	-61.00	-63.58	------	------	------	------
1104	66.87	66.95	66.18	51.50	44.42	42.84	43.83	118.97	74.60	40.42	133.53
1105	-18.20	-17.93	-17.37	-6.60	1.79	2.52	2.21	-48.79	------	------	------

(b) Constants for measuring bending moment. U. S. Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Bending moment, in-lb/μ										
104	417.70	401.11	503.52	522.63	510.37	498.92	683.67	698.86	707.27	1107.10	1235.08
105	-76.61	-62.91	-133.76	-169.44	-------	-------	-------	-------	-------	-------	-------
304	561.51	631.41	406.40	602.43	327.25	490.67	-------	-------	-------	-------	-------
305	-92.38	-150.26	-------	-------	-------	-------	-------	-------	-------	-------	-------
504	523.61	429.29	381.51	406.29	408.13	-------	-------	-------	-------	-------	-------
505	-91.99	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
704	763.90	801.72	949.07	544.95	784.19	934.16	1183.74	1125.72	1405.23	-------	-------
705	-137.38	-191.94	-288.48	-------	-------	-------	-------	-------	-------	-------	-------
904	841.54	851.30	850.49	1056.26	1247.22	1332.87	1343.98	413.88	610.89	1710.13	-------
905	-220.65	-215.01	-188.70	-438.13	-516.63	-539.93	-562.73	-------	-------	-------	-------
1104	591.90	592.63	585.77	464.70	393.20	379.22	387.97	1053.01	660.32	357.78	1181.86
1105	-161.10	-158.71	-153.74	-58.44	15.82	22.33	19.56	-431.89	-------	-------	-------

TABLE 1.—Continued

(c) Constants for measuring torque. SI Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Torque, m-N/μ										
104	-19.46	-19.16	-16.56	1.72	9.17	------	------	------	------	------	------
105	11.66	11.62	11.55	7.20	------	------	------	------	------	------	------
304	0.99	------	------	------	------	------	------	------	------	------	------
305	30.47	30.67	30.42	35.23	34.38	49.79	------	------	------	------	------
504	24.42	24.78	------	------	------	------	------	------	------	------	------
505	47.37	47.24	51.43	46.31	45.44	36.02	86.86	81.38	141.82	------	------
704	44.80	45.14	61.44	------	------	------	------	------	------	------	------
705	64.60	64.54	59.52	75.06	76.02	77.48	63.74	65.18	------	------	------
904	70.28	70.20	74.54	115.96	121.20	123.68	137.25	------	------	------	------
905	67.96	68.00	67.98	57.35	56.81	57.70	59.77	100.63	79.97	210.60	32.00
1104	72.41	72.43	72.08	60.13	58.43	55.62	52.50	127.08	135.34	163.35	------
1105	92.33	92.31	92.58	93.75	93.48	91.75	80.06	38.82	38.54	-16.80	211.20

(c) Constants for measuring torque. U. S. Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Torque, in-lb/μ										
104	-172.20	-169.61	-146.58	15.21	81.14	-------	-------	-------	-------	-------	-------
105	103.20	102.82	102.20	63.72	-------	-------	-------	-------	-------	-------	-------
304	8.49	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
305	269.69	271.44	269.25	311.87	304.31	440.69	-------	-------	-------	-------	-------
504	216.17	219.29	-------	-------	-------	-------	-------	-------	-------	-------	-------
505	419.28	418.18	455.26	409.94	402.20	318.86	768.78	720.31	1255.29	-------	-------
704	396.56	399.56	543.93	-------	-------	-------	-------	-------	-------	-------	-------
705	571.79	571.24	526.86	664.37	672.84	685.75	564.15	576.94	-------	-------	-------
904	622.04	621.40	659.76	1026.45	1072.80	1094.76	1214.90	-------	-------	-------	-------
905	601.51	601.90	601.71	507.61	502.86	510.72	529.06	890.73	707.86	1864.06	283.21
1104	640.89	641.12	638.03	532.20	517.16	492.34	464.67	1124.86	1197.94	1445.88	-------
1105	817.20	817.07	819.48	829.77	827.41	812.12	708.63	343.58	341.10	-148.73	1869.38

TABLE 2.—LOAD EQUATION CONSTANTS DERIVED WITH MT METHOD

(a) Constants for measuring shear. SI Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Shear, N/μ										
104	12.23	11.79	10.59	16.99	18.55	19.26	34.43	39.00	29.67	41.86	44.92
105	32.96	33.18	32.87	32.02	31.49	26.78	-----	-----	-----	------	-----
304	13.88	18.90	18.64	-----	-----	-----	-----	-----	-----	------	-----
305	31.00	29.89	29.80	33.58	33.67	52.31	78.77	77.97	65.65	------	-----
504	12.10	-----	-----	-----	-----	-----	-----	-----	-----	------	-----
505	33.72	36.12	36.47	35.23	30.69	-----	-----	-----	-----	------	-----
704	18.24	23.22	30.51	41.54	41.86	35.45	14.81	-----	-----	------	-----
705	32.34	30.56	28.47	25.89	50.66	67.88	62.40	65.83	87.67	114.76	-----
904	18.15	20.28	-----	-----	-----	-----	-----	-----	-----	------	-----
905	29.09	28.82	34.12	34.92	-----	-----	-----	-----	-----	------	-----
1104	15.74	15.48	25.80	26.07	17.04	17.92	12.99	16.37	37.72	30.51	37.72
1105	30.16	30.34	26.60	26.42	44.75	42.26	42.74	40.61	-----	------	-----

(a) Constants for measuring shear. U. S. Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Shear, lb/μ										
104	2.75	2.65	2.38	3.82	4.17	4.33	7.74	8.77	6.67	9.41	10.10
105	7.41	7.46	7.39	7.20	7.08	6.02	-----	-----	-----	-----	-----
304	3.12	4.25	4.19	----	-----	-----	-----	-----	-----	-----	-----
305	6.97	6.72	6.70	7.55	7.57	11.76	17.71	17.53	14.76	-----	-----
504	2.72	----	----	----	-----	-----	-----	-----	-----	-----	-----
505	7.58	8.12	8.20	7.92	6.90	-----	-----	-----	-----	-----	-----
704	4.10	5.22	6.86	9.34	9.41	7.97	3.33	-----	-----	-----	-----
705	7.27	6.87	6.40	5.82	11.39	15.26	14.03	14.80	19.71	25.80	-----
904	4.08	4.56	----	----	-----	-----	-----	-----	-----	-----	-----
905	6.54	6.48	7.67	7.85	-----	-----	-----	-----	-----	-----	-----
1104	3.54	3.48	5.80	5.86	3.83	4.03	2.92	3.68	8.48	6.86	8.48
1105	6.78	6.82	5.98	5.94	10.06	9.50	9.61	9.13	-----	-----	-----

TABLE 2.—Continued

(b) Constants for measuring bending moment. SI Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Bending moment, m-N/μ										
104	47.19	44.96	45.18	38.82	37.92	52.38	50.65	30.68	24.99	------	------
105	-8.66	-7.70	-7.91	------	------	------	------	------	------	------	------
304	63.44	87.97	87.44	93.93	86.43	31.27	74.92	130.03	127.33	176.92	249.37
305	-10.44	16.00	15.16	23.77	21.92	------	------	------	------	------	------
504	59.16	------	------	------	------	------	------	------	------	------	------
505	-10.39	0.11	------	------	------	------	------	------	------	------	------
704	86.30	110.66	110.68	111.66	128.30	167.00	89.43	89.63	126.30	116.86	------
705	-15.52	-24.08	-23.38	-20.34	-36.15	-53.90	------	------	------	------	------
904	95.08	105.70	105.83	108.62	74.04	85.59	50.82	73.51	------	------	------
905	-24.93	-26.11	-26.24	-27.39	------	------	------	------	------	------	------
1104	66.87	65.51	65.46	65.32	87.90	81.23	113.52	70.22	99.99	96.38	107.83
1105	-18.20	-17.27	-17.29	-16.80	-32.95	-26.98	-45.58	------	------	------	------

(b) Constants for measuring bending moment. U. S. Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Bending moment, in-lb/μ										
104	417.71	397.92	399.90	343.56	335.68	463.59	448.33	271.52	222.19	-------	-------
105	-76.61	-68.18	-70.03	-------	-------	-------	-------	-------	-------	-------	-------
304	561.51	778.61	773.95	831.36	765.03	276.82	663.16	1150.90	1127.04	1565.96	2207.25
305	-92.38	-141.58	-134.15	-210.41	-194.06	-------	-------	-------	-------	-------	-------
504	532.61	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
505	-91.99	-11.12	-------	-------	-------	-------	-------	-------	-------	-------	-------
704	763.90	979.50	979.66	988.34	1135.57	1478.12	791.58	793.86	1117.93	1034.37	-------
705	-137.38	-213.17	-206.98	-180.02	-320.00	-477.12	-------	-------	-------	-------	-------
904	841.54	935.60	936.69	961.46	655.38	757.53	449.79	650.69	-------	-------	-------
905	-220.65	-231.14	-232.28	-242.39	-------	-------	-------	-------	-------	-------	-------
1104	591.90	579.83	579.39	578.12	778.04	718.96	1004.78	621.53	885.07	853.08	954.42
1105	-161.10	-152.88	-153.01	-148.72	-291.68	-238.84	-403.42	-------	-------	-------	-------

TABLE 2.—Continued

(c) Constants for measuring torque. SI Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Torque, m-N/μ										
104	-19.45	-19.16	-22.86	-20.46	-----	------	------	------	------	------	------
105	11.66	11.62	24.67	24.51	17.95	21.92	28.33	28.48	165.93	157.59	219.77
304	0.96	------	------	------	-----	------	------	------	------	------	------
305	30.47	30.67	------	------	-----	------	------	------	------	------	------
504	24.42	24.78	22.65	------	-----	------	------	------	------	------	------
505	47.37	47.24	70.02	73.69	76.43	71.75	------	------	------	------	------
704	44.80	45.14	55.06	69.91	16.26	------	------	------	------	------	------
705	64.60	64.54	57.96	53.42	63.43	70.42	135.24	155.56	------	------	------
904	70.28	70.20	69.13	73.11	95.58	121.28	96.57	142.49	159.05	207.22	------
905	67.96	68.00	68.44	68.42	68.42	56.11	44.11	------	------	------	------
1104	72.41	72.43	75.32	74.98	69.57	61.52	74.20	38.64	28.58	------	------
1105	92.33	92.31	91.44	91.67	93.27	92.84	90.34	118.84	101.42	110.46	123.34

(c) Constants for measuring torque. U. S. Units

Strain gage number	Number of strain gages										
	12	11	10	9	8	7	6	5	4	3	2
	Torque, in-lb/μ										
104	-172.20	-196.61	-202.39	-181.08	------	-------	-------	-------	-------	-------	-------
105	103.20	102.82	218.38	216.96	158.92	194.05	250.83	252.11	146.68	1394.84	1945.21
304	8.49	-------	-------	-------	------	-------	-------	-------	-------	-------	-------
305	269.69	271.44	-------	-------	------	-------	-------	-------	-------	-------	-------
504	216.17	219.29	200.50	-------	------	-------	-------	-------	-------	-------	-------
505	419.28	418.18	619.77	652.21	676.54	635.11	-------	-------	-------	-------	-------
704	396.56	399.56	487.37	618.81	143.96	-------	-------	-------	-------	-------	-------
705	571.79	571.24	513.01	472.84	561.42	623.29	1197.06	1376.93	-------	-------	-------
904	622.04	621.40	611.92	647.09	845.97	1073.46	854.78	1261.19	1407.76	1834.15	-------
905	601.51	601.90	605.82	605.62	534.77	496.67	390.47	-------	-------	-------	-------
1104	640.89	641.12	666.66	663.64	615.74	544.51	656.81	341.97	252.93	-------	-------
1105	817.20	817.07	809.14	811.40	825.52	821.78	799.59	1051.84	897.66	977.66	1091.67

TABLE 3.—DIFFERENCE BETWEEN CALCULATED AND APPLIED LOADS

(a) Loads with forward center of pressure. Applied shear, 48,492 N (10,902 lb); applied bending, 20,616 m-N (802,058 in-lb); applied torque, 64,143 m-N (567,744 in-lb).

Number of strain gages in equation	T method	MT method	T method	MT method	T method	MT method
	Difference in shear, percent		Difference in bending, percent		Difference in torque, percent	
12	0	0	0	0	-2	-2
11	0	-1	-1	-2	-2	-2
10	3	-1	1	-2	-1	-1
9	6	3	0	-3	1	0
8	5	2	6	-3	0	2
7	-4	1	5	4	-1	2
6	-22	0	13	3	-4	2
5	-27	1	14	0	-9	3
4	-34	-2	19	-2	-11	-6
3	-30	-2	24	-10	-20	-4
2	-42	-29	21	-20	-78	-35

(c) Loads with aft center of pressure. Applied shear, 48,252 N (10,848 lb); applied bending, 95,818 m-N (848,108 in-lb); applied torque, 110,612 m-N (979,050 in-lb).

Number of strain gages in equation	T method	MT method	T method	MT method	T method	MT method
	Difference in shear, percent		Difference in bending, percent		Difference in torque, percent	
12	-2	-2	-5	-5	-5	-5
11	-3	-3	-5	-6	-6	-5
10	0	-5	-4	-6	-5	-5
9	2	-2	-3	-6	-2	-4
8	-1	-3	0	-7	-2	-2
7	-6	-5	0	-2	-3	-1
6	-27	-6	4	-3	-4	-3
5	-28	-5	2	-2	-10	-1
4	-35	-10	8	-7	-12	-5
3	-32	-10	17	-11	-14	-3
2	-44	-36	6	-17	-48	-17

(b) Loads with midcenter of pressure. Applied shear, 88,182 N (19,825 lb); applied bending, 173,136 m-N (1,532,457 in-lb); applied torque, 200,990 m-N (1,779,003 in-lb).

Number of strain gages in equation	T method	MT method	T method	MT method	T method	MT method
	Difference in shear, percent		Difference in bending, percent		Difference in torque, percent	
12	0	0	-1	-1	0	0
11	-1	-1	-1	-1	0	0
10	1	-3	0	-1	0	0
9	4	0	0	-1	2	1
8	0	-2	5	-2	2	2
7	-4	-4	4	2	1	3
6	-26	-6	9	0	1	0
5	-28	-6	5	1	-6	3
4	-33	-11	12	-2	-8	0
3	-30	-12	20	-7	-10	2
2	-41	-36	8	-13	-44	-10

TABLE 4.—EQDE PROGRAM

```
 1   ********** E C H O   O F   E Q D E   C O N T R O L   D A T A   I N P U T **********

              1        10        20        30        40        50        60        70        80
              !         !         !         !         !         !         !         !         !
CARD NO.      V         V         V         V         V         V         V         V         V
      1       HWTS LOADS EQNS ROOM TEMP CALIB (2000 LB PT LOAD)
      2            104  900       105  901       304  902       305  903       504  904       505  905
      3            704  906       705  907       904  908       905  909      1104  910      1105  911
      4       LASTGAGE
      5        $PROCES $
      6       1 28C
      7       2.1.5               1         1         1    200.
      8          701     37.6      120.
      9       2.2.5               1         2         1    200.
     10          701     37.6      100.
     11       2.3.5               1         3         1    200.
     12          702     37.6       80.
     13       2.4.5               1         4         1
     14          702     37.6       60.
     15       2.5.5               1         5         1
     16          717     37.6       40.
     17       2.6.5               1         6         1
     18          717     37.6       20.
     19       2.7.5               1         7         1
     20          704     81.3      120.
     21       2.8.5               1         8         1
     22          704     81.3      100.
     23       2.9.5               1         9         1
     24          703     81.3       80.
     25       2.10.5              1        10         1      0.
     26          703     81.3       60.
     27       LASTLOAD
     28       SHEAR   510          10
     29            104       105       305       505       704       705       904       905      1104      1105
     30       SHEAR   609           9
     31            104       105       305       505       704       705       905      1104      1105
     32       SHEAR   608           8
     33            104       105       305       505       704       905      1104      1105
     34       BENDING 610          10
     35            104       105       304       305       704       705       904       905      1104      1105
     36       TORQUE  510          10
     37            104       105       305       505       704       705       904       905      1104      1105
     38       LASTEQU
```

2 CURSORY CHECK OF EQDE CONTROL DATA CARDS REVEALS NO ERRORS

TABLE 4.—Continued

```
HWTS LOADS EQNS ROOM TEMP CALIB (2000 LB PT LOAD)

********* E Q D E   P R O C E S S I N G   I N F O R M A T I O N *********
*                                                                        *
*                                                                        *
*            DATE JOB RUN ...................... 03/05/77                *
*                                                                        *
*            TIME JOB RUN ...................... 12.59.26.               *
*                                                                        *
*            TOTAL NO. OF GAGES ................ 12                      *
*                                                                        *
*            TOTAL NO. OF LOAD CONDITIONS ...... 10                      *
*                                                                        *
*            TOTAL NO. OF EQUATIONS ............  5                      *
*                                                                        *
*            INPUT DATA SET ....................TAPE                     *
*                                                                        *
*            PRINT INFLUENCE COEFFICIENTS ......YES                      *
*                                                                        *
*            PRINT INTERCORRELATION TABLE ......YES                      *
*                                                                        *
*            PRINT INFLU. COEFF. SUMMATION .....YES                      *
*                                                                        *
*            TABLE OF RESIDUALS ................MEAN/STD                 *
*                                                                        *
*            PUNCH INFLUENCE COEFFICIENTS ......NO                       *
*                                                                        *
*            PUNCH EQUATION COEFFICIENTS .......NO                       *
*                                                                        *
*                                                                        *
**************************************************************************
```

3

TABLE 4.—Continued

HWTS LOADS EQNS ROOM TEMP CALIB (2000 LB PT LOAD)

```
***************************************************************************************************************
* INFLUENCE COEFFICIENTS FOR LOAD CONDITION 2.1.5       DATA SET = 280 (FILE =  1)       NO. OF DATA POINTS = 339 *
*                                                                                                             *
* DATA SET FILE TITLE = HWTS TEST R.T.       2.1.5     SINGLE PT.          8/31/76                            *
*                                                                                                             *
* LOAD CELL DATA RECORDING CHANNEL(S):  701                                          LOAD <  200.0 LBS DELETED *
***************************************************************************************************************
   BENDING ARM: MEAN =  37.60  STD DEV =    0.00      TORQUE ARM: MEAN = 120.00  STD DEV =    0.00
```

4

5

GAGE ID	DATA RECORDING CHANNEL	CORRELATION	INFLUENCE COEFFICIENT	STANDARD ERROR
104	900	.9859	.00531015	.00005380
105	901	-.9885	-.00686782	.03005723
304	902	.9902	.00626733	.00004826
305	903	.8100	.00134114	.00007262
504	904	.9747	.00773997	.00009753
505	905	.9837	.00537548	.00005547
704	906	.9454	.00592789	.00011137
705	907	.9977	.01175584	.00004332
904	908	.9937	.01803672	.00011118
905	909	.9984	.02430367	.00007722
1104	910	.9989	.04317849	.00010822
1105	911	.9998	.06456749	.00007256

6 7 8

HWTS LOADS EQNS ROOM TEMP CALIB (2000 LB PT LOAD)

9 GAGE INTERCORRELATION MATRIX

GAGE ID	104	105	304	305	504	505	704	705	904	905	1104	1105
104	1.00000	.68829	.96374	.71871	.84076	.45540	.81694	.21465	.20173	-.15291	.04832	-.26352
105	.68829	1.00000	.52737	.79033	.23893	.30381	.20649	-.12341	-.44849	-.45213	-.52407	-.61464
304	.96374	.52737	1.00000	.69555	.92589	.50848	.89976	.31308	.37945	-.04206	.22637	-.12473
305	.71871	.79033	.69555	1.00000	.47945	.67834	.45496	.21437	-.17767	-.22618	-.28854	-.44645
504	.84076	.23893	.92589	.47945	1.00000	.52793	.95469	.43664	.62699	.13992	.48420	.11074
505	.45540	.30381	.50848	.67834	.52793	1.00000	.54609	.66283	.13002	.17311	-.00107	-.13137
704	.81694	.20649	.89976	.45496	.95469	.54609	1.00000	.57817	.60908	.19946	.44169	.08629
705	.21465	-.12341	.31308	21437	.43664	.66283	.57817	1.00000	.48060	.64256	.35675	.31055
904	.20173	-.44849	.37945	-.17767	.62699	.13002	.60908	.48060	1.00000	.62872	.95716	.73509
905	-.15291	-.45213	-.04206	-.22618	.13992	.17311	.19946	.64256	.62872	1.00000	.59411	.76401
1104	.04832	-.52407	.22637	-.28854	.48420	-.00107	.44169	.35675	.95716	.59411	1.00000	.84251
1105	-.26352	-.61464	-.12473	-.44645	.11074	-.13137	.08629	.30055	.73509	.76401	.84251	1.00000

TABLE 4.—Continued

HHTS LOADS EQNS ROOM TEMP CALIB (2000 LB PT LOAD)

10 INFLUENCE COEFFICIENT SUMMARY

LOAD CONDITION/ MEAN BENDING ARM/ MEAN TORQUE ARM	GAGE IDS AND INFLUENCE COEFFICIENTS 104	105	304	305	504	505	704	705
2.1.5 / 37.60/ 120.00	.00581	-.00587	.00627	.00184	.00780	.00558	.00593	.01176
2.2.5 / 37.60/ 100.00	.01027	-.00194	.00903	.00612	.00932	.01070	.00938	.01902
2.3.5 / 37.60/ 80.00	.01421	.00435	.01167	.01163	.01109	.01804	.01449	.03331
2.4.5 / 37.60/ 60.00	.02008	.01396	.01509	.02063	.01382	.03213	.01217	.01814
2.5.5 / 37.60/ 40.00	.02709	.02961	.02008	.03804	.01235	.01823	.01140	.01075
2.6.5 / 37.60/ 20.00	.03748	.06143	.01979	.02705	.01232	.01089	.01074	.00572
2.7.5 / 81.30/ 120.00	.01286	-.01005	.01353	.00465	.01468	.00755	.01298	.01194
2.8.5 / 81.30/ 100.00	.02187	-.00228	.01838	.00868	.01689	.00978	.01706	.01323
2.9.5 / 81.30/ 80.00	.03024	.00623	.02295	.01208	.01878	.01081	.02072	.01290
2.10.5 / 81.30/ 60.00	.04088	.01612	.02747	.01506	.02174	.01095	.02104	.01232

	904	905	1104	1105
2.1.5 / 37.60/ 120.00	.01810	.02490	.04318	.06457
2.2.5 / 37.60/ 100.00	.01930	.03627	.02780	.03129
2.3.5 / 37.60/ 80.00	.01283	.01874	.01821	.01424
2.4.5 / 37.60/ 60.00	.00963	.01031	.01130	.00472
2.5.5 / 37.60/ 40.00	.00697	.00517	.00595	-.00090
2.6.5 / 37.60/ 20.00	.00362	.00103	.00123	-.00675
2.7.5 / 81.30/ 120.00	.02927	.01428	.06653	.04211
2.8.5 / 81.30/ 100.00	.02672	.01202	.04961	.02895
2.9.5 / 81.30/ 80.00	.02129	.01033	.03646	.01730
2.10.5 / 81.30/ 60.00	.01715	.00807	.02415	.00700

TABLE 4.—Concluded

HWTS LOADS EQNS ROOM TEMP CALIB (2000 LB PT LOAD)

LOAD = SHEAR   EQUATION 510

MULTIPLE REGRESSION ANALYSIS

GAGE ID	EQUATION COEFFICIENT 11	STANDARD ERROR 12	T VALUE 13
104	6.220	.113021	55.0337
105	6.584	.047992	137.1876
305	7.565	.049735	152.1176
505	8.020	.054515	147.1181
704	4.235	.210904	20.0779
705	7.195	.073763	97.5473
904	4.315	.167039	25.8311
905	6.601	.066745	98.8952
1104	3.646	.086760	42.0242
1105	6.797	.046199	147.1321

GAGE/LOAD DATA ANALYSIS

GAGE ID	MEAN 14	STANDARD DEVIATION 15	GAGE/LOAD CORRELATION 16
104	26.3048	18.9409	.65977015
105	13.7211	26.7300	.23616411
305	16.3398	15.9112	.52513876
505	15.6127	11.8877	.64409630
704	13.4984	9.5952	.79807935
705	17.9158	12.1561	.69296299
904	21.7523	14.3217	.65147700
905	16.6450	14.8863	.53484694
1104	33.0058	28.9866	.55276688
1105	21.9153	28.1882	.39890549
LOAD/SHEAR	1117.9549	565.1947	

17 INTERCEPT OF EQUATION .... -43.9367

18 STANDARD ERROR OF EQUATION 18.0883

19 MULTIPLE CORRELATION .... .9995

20 TABLE OF RESIDUALS

LOAD CONDITION	DATA SET	FILE	NO. OF POINTS	MEAN ERROR 21	STANDARD DEVIATION 22
2.1.5	28C	1	339	-.34	13.81
2.2.5	28C	2	337	.68	13.14
2.3.5	28C	3	337	2.71	20.92
2.4.5	28C	4	338	.75	19.47
2.5.5	28C	5	336	-1.19	20.10
2.6.5	28C	6	334	.53	13.87
2.7.5	28C	7	335	4.10	21.90
2.8.5	28C	8	333	-4.55	14.74
2.9.5	28C	9	328	-6.28	21.07
2.10.5	28C	10	431	2.65	18.70

23 EQUATION RMS ERROR/RMS LOAD = .0144 (1.44 %)

$\boxed{1}$ All data control card input is listed in this printing. Error messages will reference the card number, if that card is in error.

$\boxed{2}$ This message indicates that a preliminary form check has been performed on the data control cards. Further checks are performed later in the program.

$\boxed{3}$ This page contains processing information concerning this job execution and thus constitutes a permanent record for this run.

$\boxed{4}$ This section contains processing information concerning each load condition. Load cells listed may be shear only, or may include bending and torque values if they also reside on a user disc data set.

$\boxed{5}$ If bending and torque arm values are read from card, this section will contain statistical analysis relating to same. Sixty-eight percent of the bending (or torque) arm values will fall within the mean plus or minus the standard deviation, assuming normal distribution of error terms.

$\boxed{6}$ Represents the correlation between the gage output and load. Plus or minus one would indicate a perfect linear association. Zero would imply no linear association. Usually the value will be close to ±0.99 if the gage output is significant. The square of the correlation coefficient (X 100) gives the percentage of change in load due to a change in the gage output.

$\boxed{7}$ Equals the slope of the linear least-squares line (strain versus load). The greater the slope (relative to other influence coefficients), the more significant will be the gage if used in an equation involving that load condition.

$\boxed{8}$ Similar to a standard deviation. Gives the confidence interval for the estimated influence coefficient. Sixty-eight percent of the measurements (strain versus load) will fall within the least-squares line (strain versus load) plus or minus the standard error, assuming normal distribution of error terms.

$\boxed{9}$ Represents a summary of the gage intercorrelations with respect to the influence coefficients for all load conditions. Plus or minus one would indicate a perfect linear association. A zero would imply no linear association. Any two gages having a correlation of one would imply that both gages should not be used in the same equation. In like manner, one gage could be used for another if they have a correlation of one.

$\boxed{10}$ Represents a summary of the influence coefficients for all gages and every load condition used in the job.

$\boxed{11}$ Computed using a multiple linear regression technique. The smaller the coefficient (relative to the other coefficients), the less significant will be the gage on the resultant load (if all gages used have similar means and variance).

$\boxed{12}$ Coefficient standard error. Gives a confidence interval for the estimated coefficients predicted on the assumption of normally distributed errors. The population coefficient is within the range (coefficient minus the standard error and coefficient plus the standard error) with a 68 percent confidence.

$\boxed{13}$ The estimated coefficient divided by its standard error. In general, the larger its value (relative to other T-values), the more significant the effect of the gage on the resultant calculated load.

$\boxed{14}$ The mean of the summed gage output for all load conditions used.

$\boxed{15}$ The standard deviation of the gage output for all load conditions used. Sixty-eight percent of the gage output will fall within the mean plus or minus the standard deviation, assuming normal distribution of error terms.

$\boxed{16}$ Represents the correlation between the gage output and load for all load conditions used. A plus or minus one would indicate a perfect linear association between all gage output and load, while a zero would imply no linear association. For an equation derived using shear load, a high correlation indicates that the gage had similar data magnitudes for each load condition with the same shear. For an equation derived using bending moment or torque loads, a high positive (negative) correlation indicates that the gage output is directly (inversely) proportional to the bending moment or torque for each load condition.

$\boxed{17}$ The intercept of the equation. In general, the closer to zero the better the equation (since one desires zero strain to produce zero load).

$\boxed{18}$ This number represents an error band if the equation is being used to calculate a load. Sixty-eight percent of these calculated loads (for this equation) would be within the applied load plus or minus the standard error, assuming normal distribution of error terms.

$\boxed{19}$ The correlation for the equation in terms of the linearities of all output of gages in the equation with respect to load. A plus or minus one would indicate a perfect linear association. A zero would imply no linear association.

$\boxed{20}$ The table of residuals may take one of two forms. The first, as shown in the sample run, is the computation of the mean error (equation estimate minus actual applied load) for all data points in the load condition. The second form is the computation of the error (residual) for each data point of each load condition up to a maximum of 100 total data points. This table helps verify the accuracy of the equation estimate for the load conditions selected.

$\boxed{21}$ The mean error is the mean of the errors (equation estimate minus actual applied load) for all data points in the load condition.

$\boxed{22}$ The standard deviation of the errors (equation estimate minus actual applied loads) for all data points in the load condition. Sixty-eight percent of these differences will be within the mean error plus or minus the standard deviation, assuming normal distribution of error terms.

$\boxed{23}$ This number is the rms of the (estimate minus applied load) errors divided by the rms of the applied load for all load conditions. In general, the smaller the number (and percentage) relative to other equations, the better the equation. This value may also be used to estimate the efficiency of the equation for calculating loads which are not used in the selected calibration load conditions. For this purpose it is best used in estimating minimum errors rather than maximum errors.

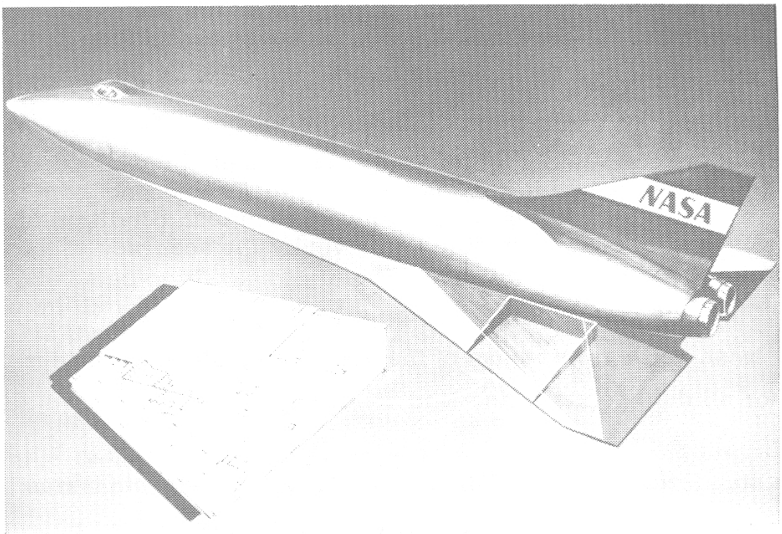


Figure 1. Hypersonic research airplane and hypersonic wing test structure.

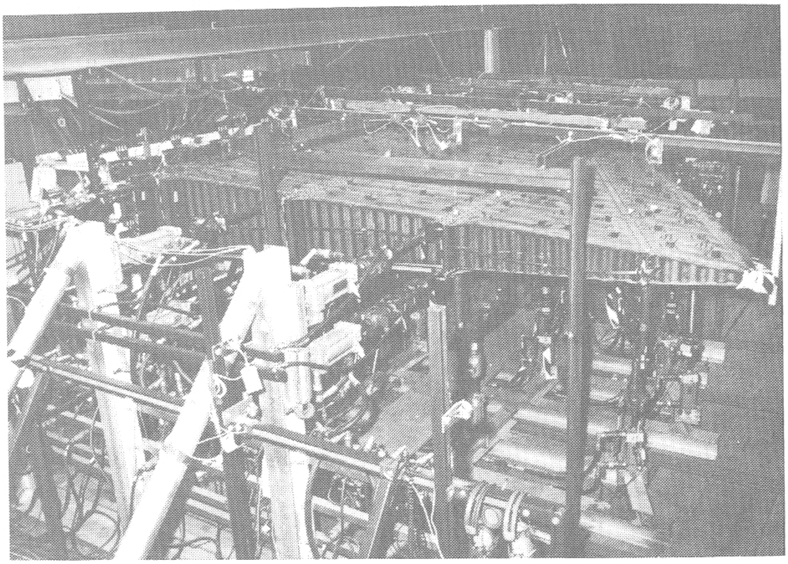


Figure 2. Hypersonic wing test structure.

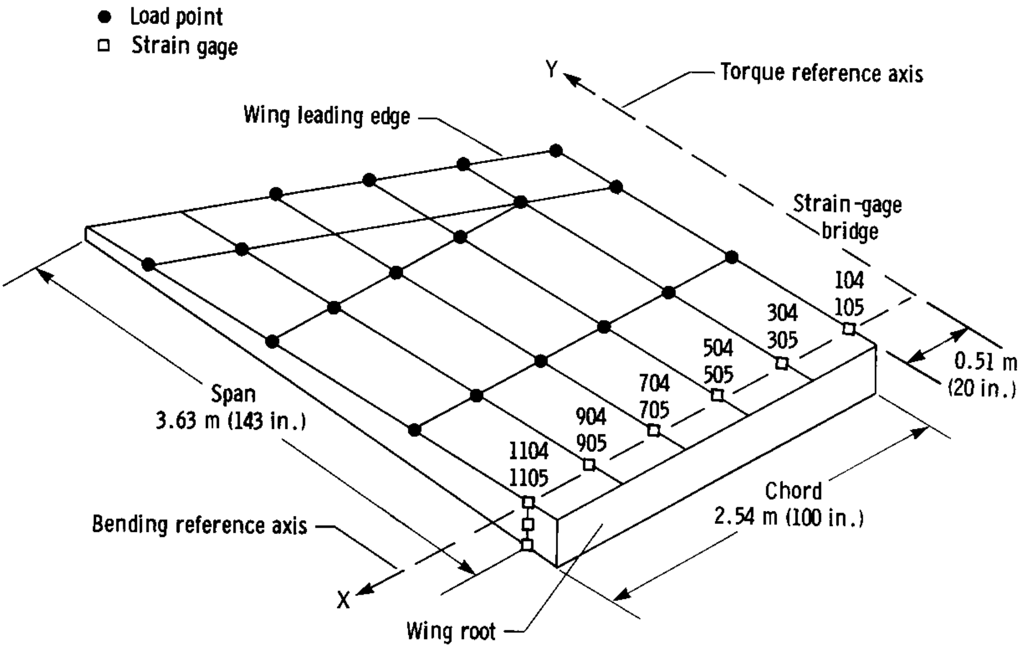
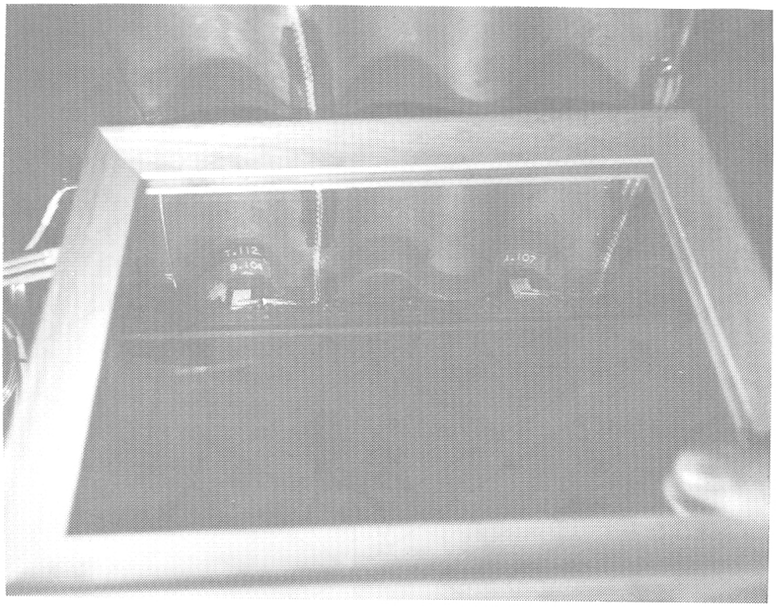
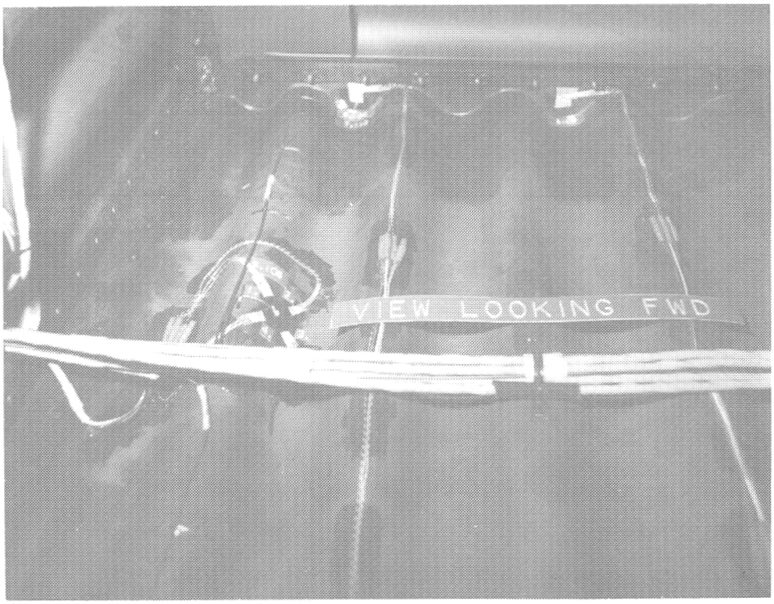


Figure 3. Strain gage bridge locations and calibration load points on the hypersonic wing test structure.



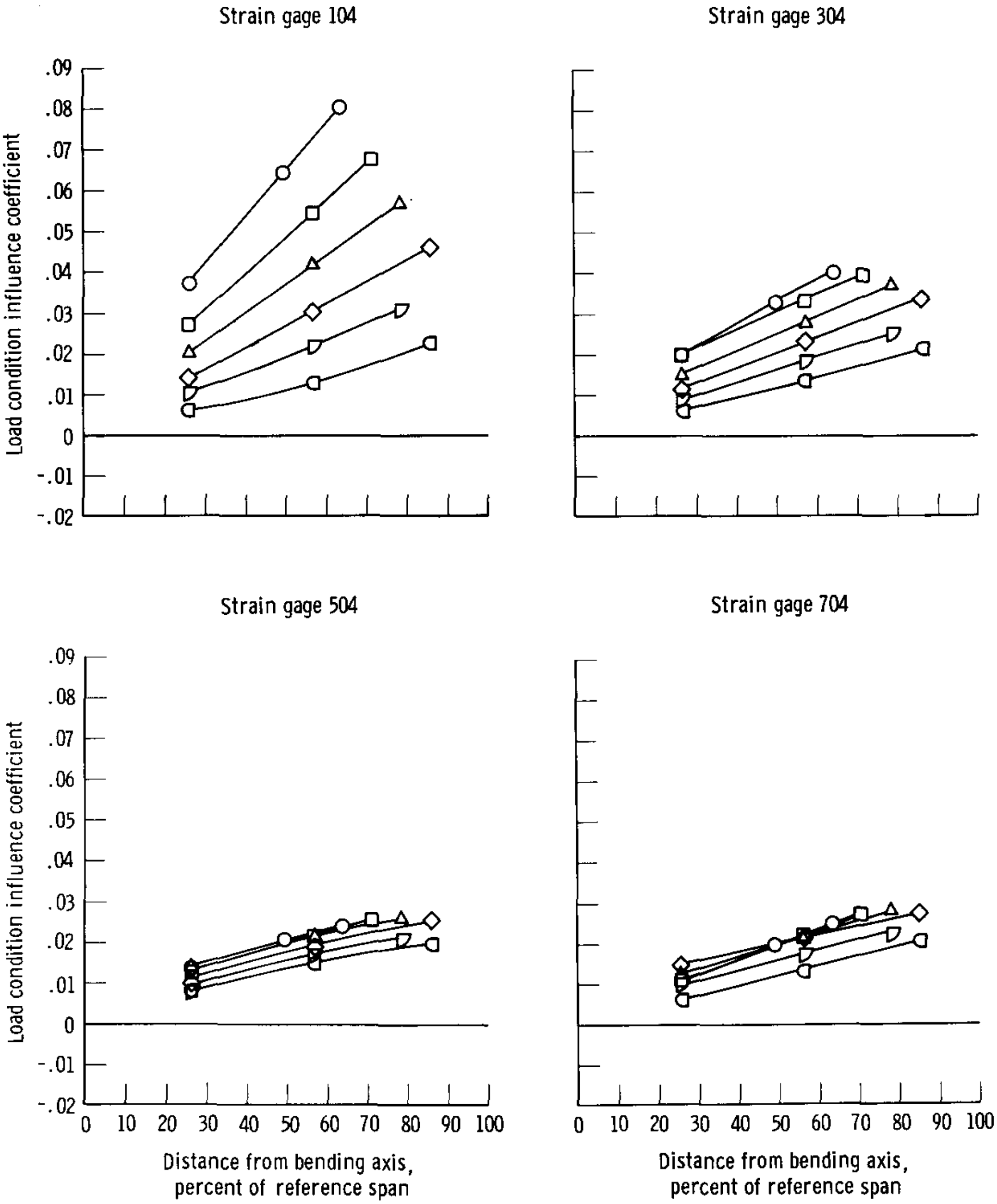
(a) Bending strain gage bridge.

Figure 4. Bending and shear strain gage bridges on hypersonic wing test structure.



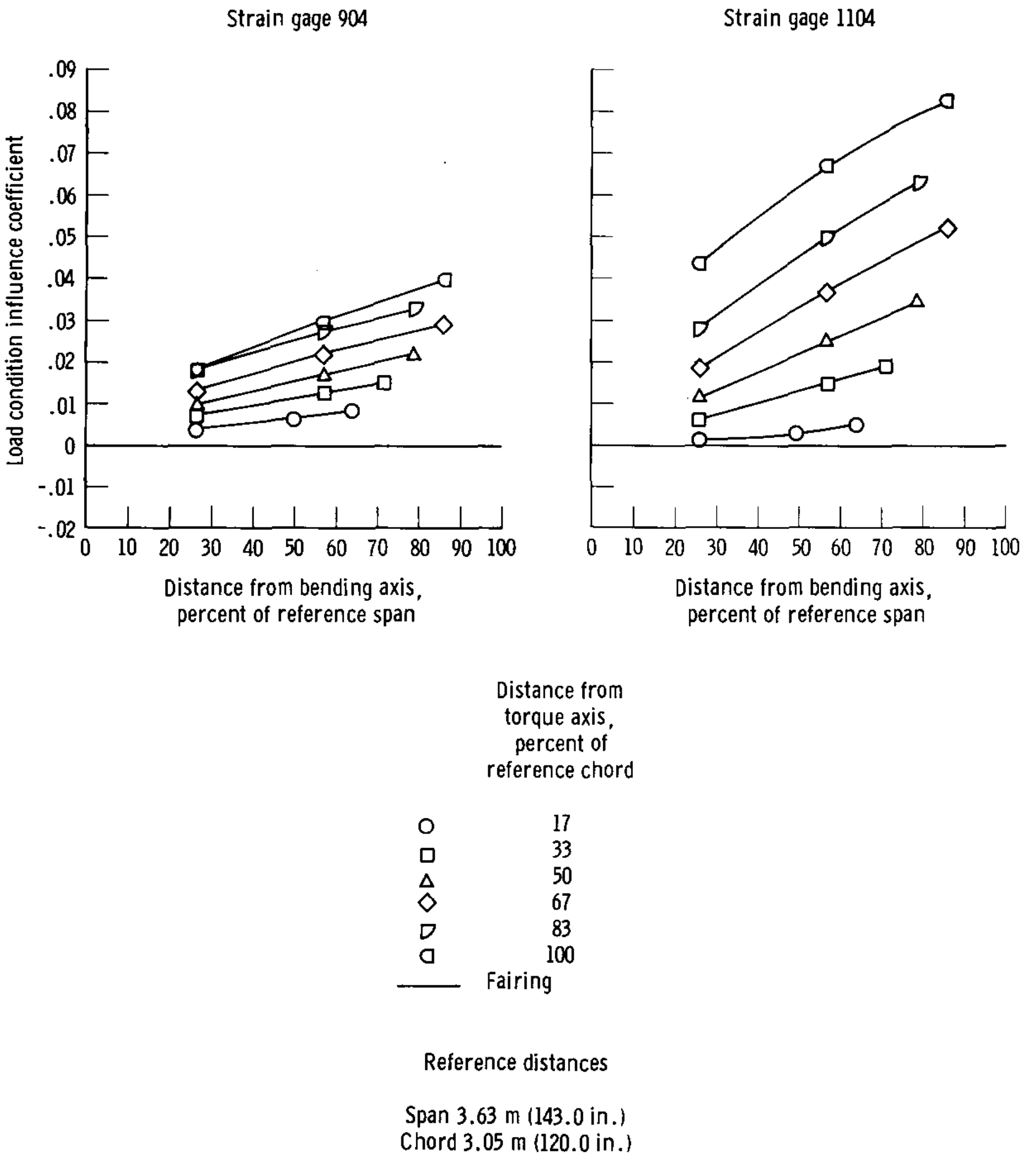
(b) Shear strain gage bridge.

Figure 4. Concluded.



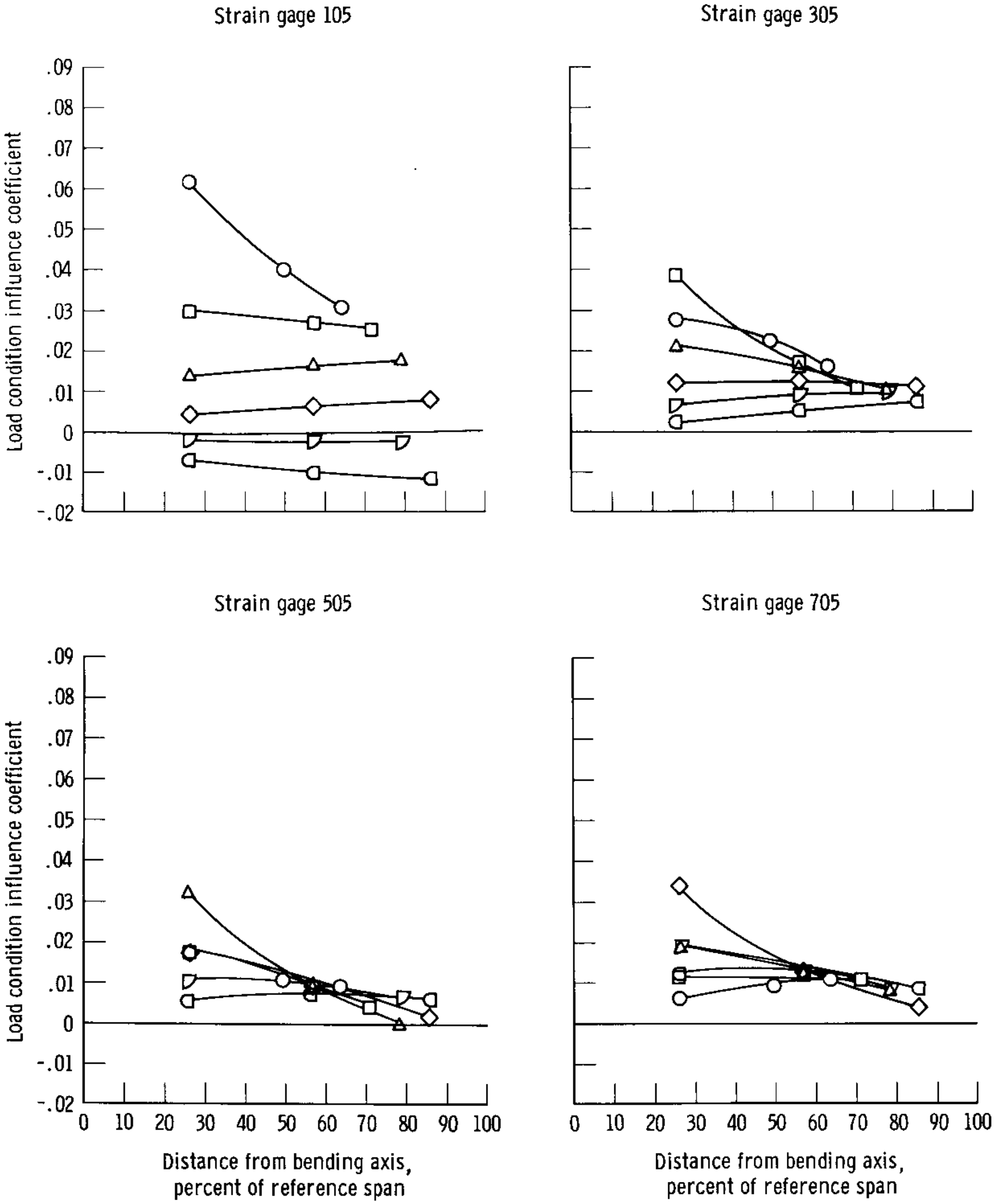
(a) Bending bridges.

Figure 5. Strain gage bridge influence coefficients.



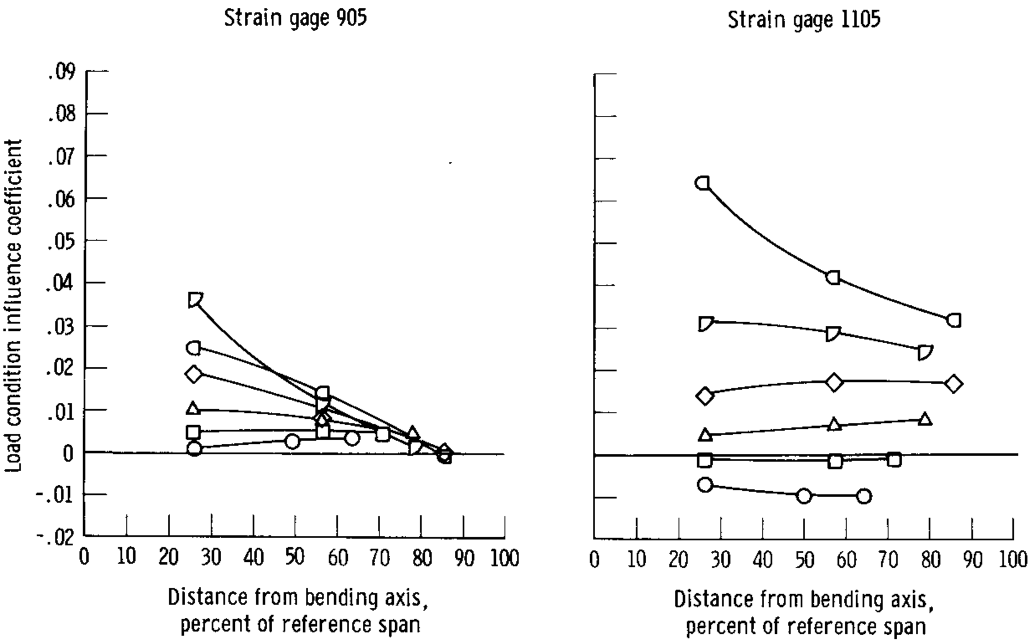
(a) Concluded.

Figure 5. Continued.



(b) Shear bridges.

Figure 5. Continued.



Distance from torque axis, percent of reference chord

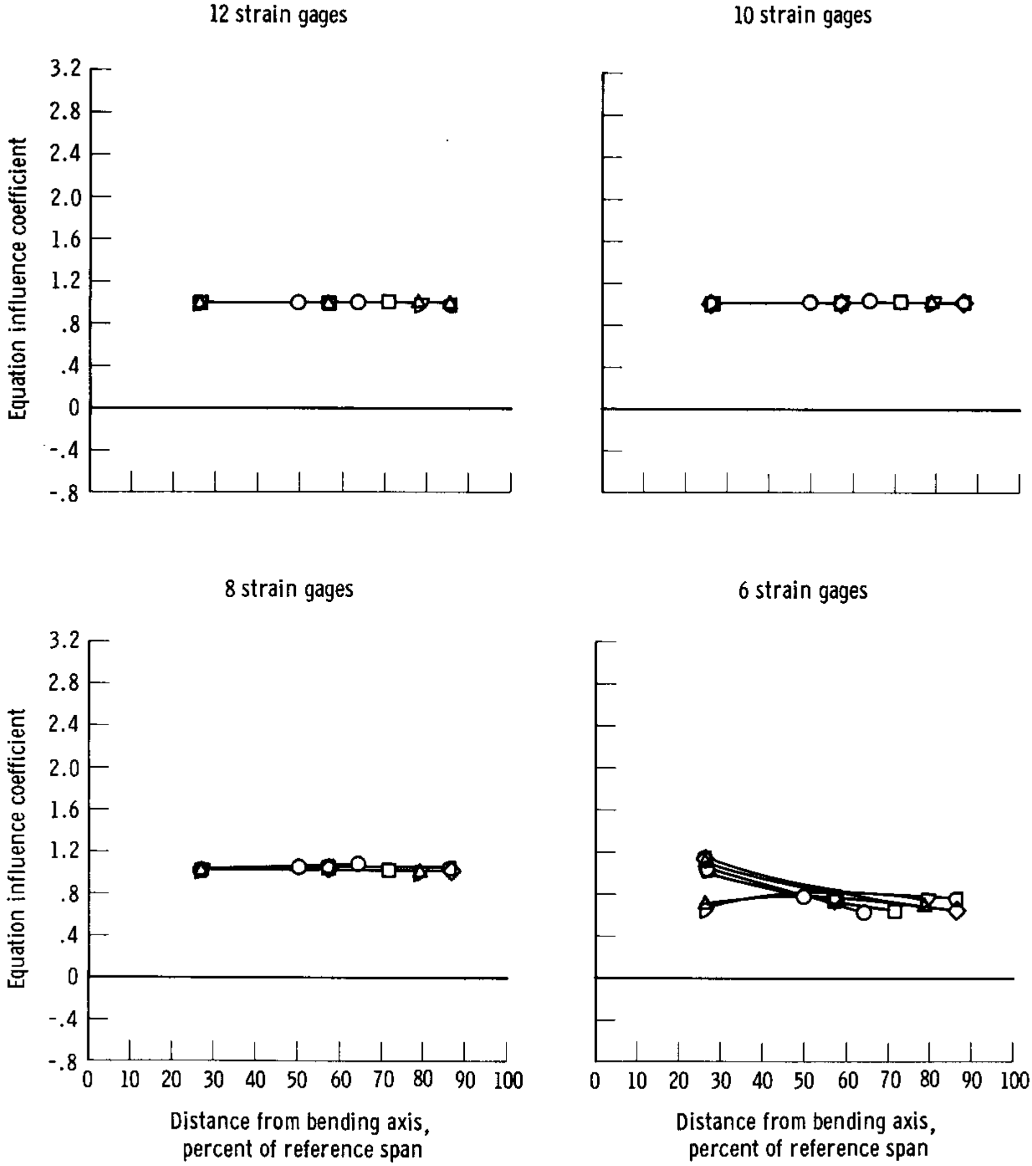
○	17
□	33
△	50
◇	67
◸	83
◿	100
———	Fairing

Reference distances

Span 3.63 m (143.0 in.)
Chord 3.05 m (120.0 in.)

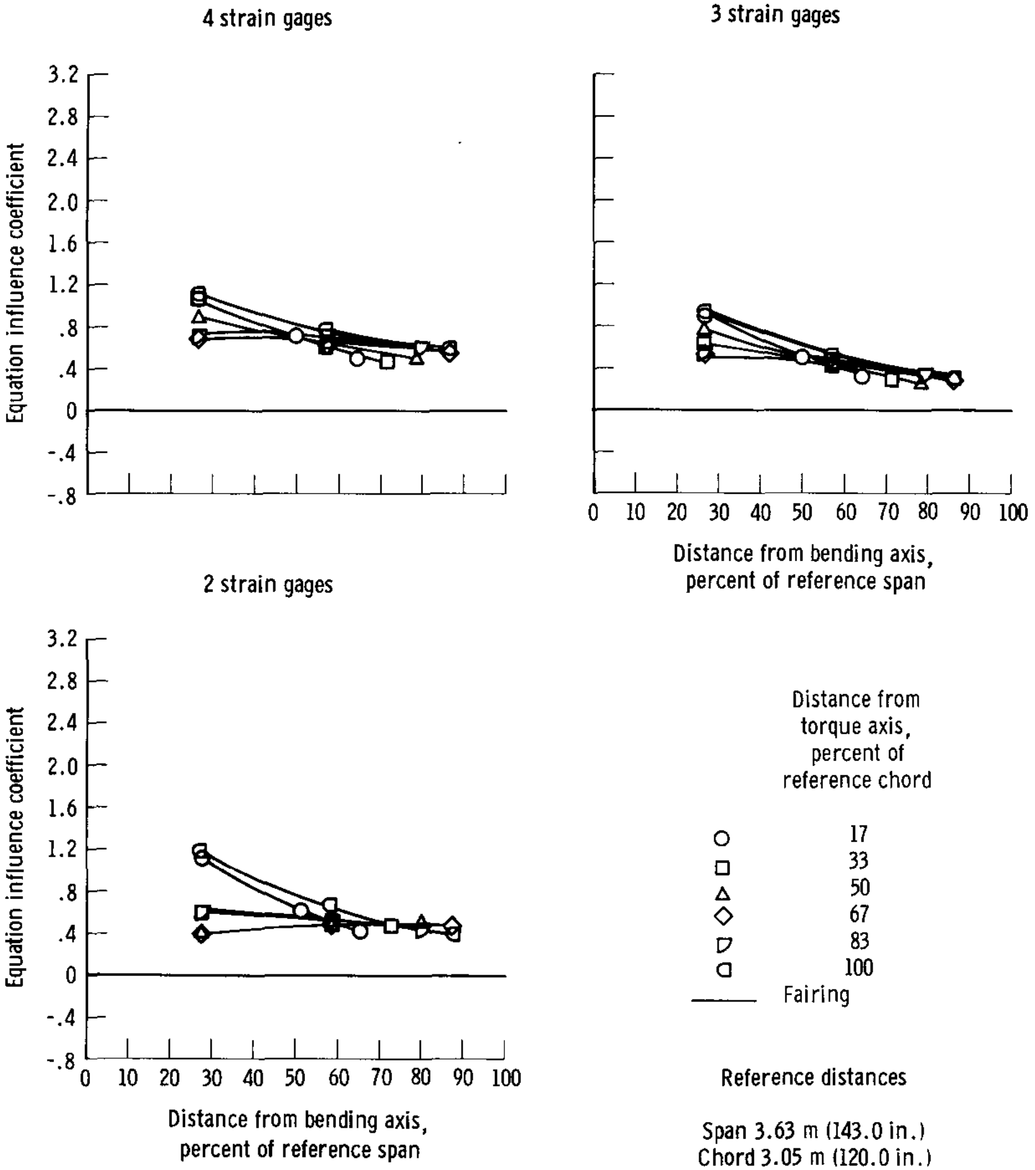
(b) Concluded.

Figure 5. Concluded.



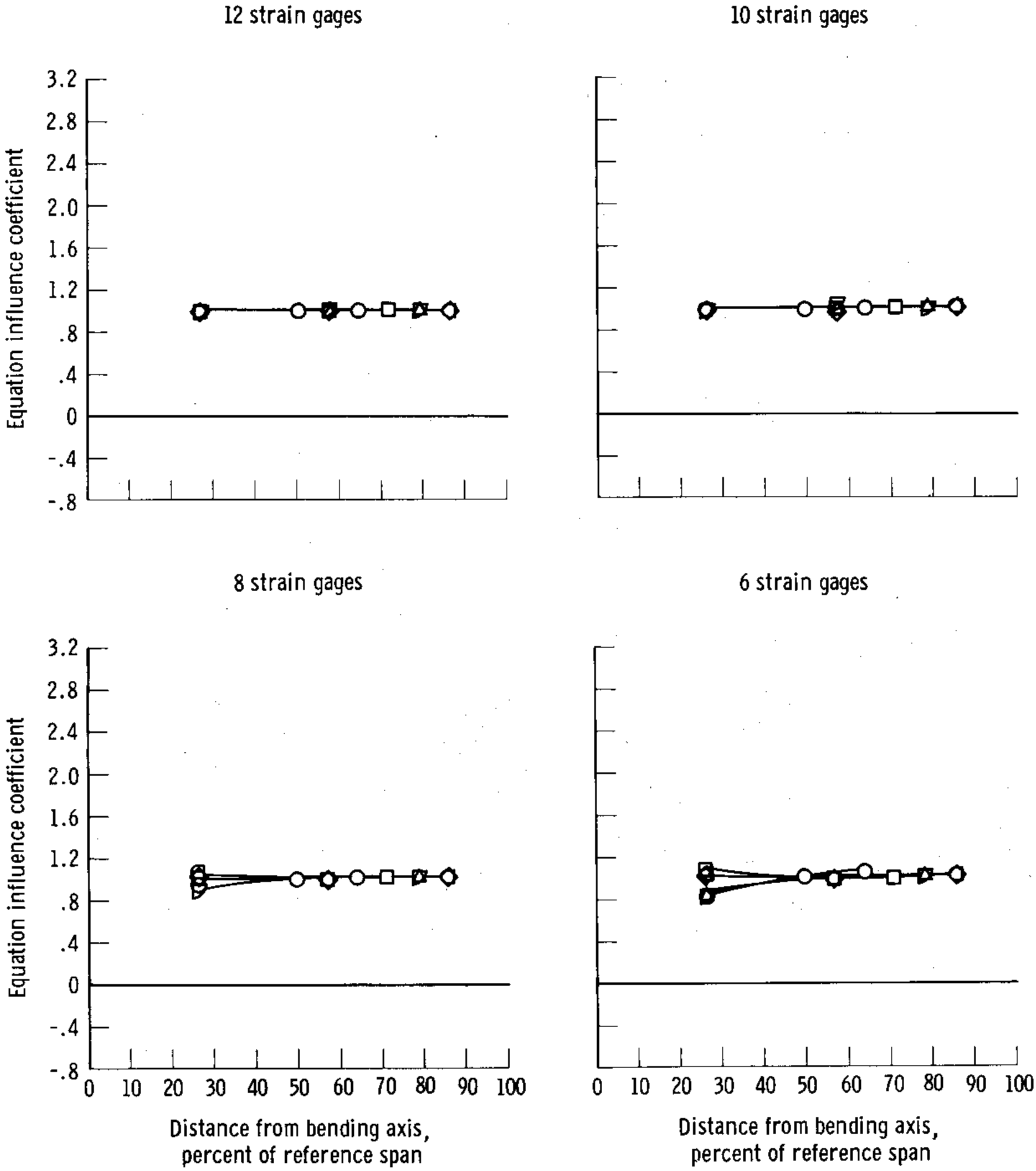
(a) T-value derived.

Figure 6. Shear equation influence coefficients.



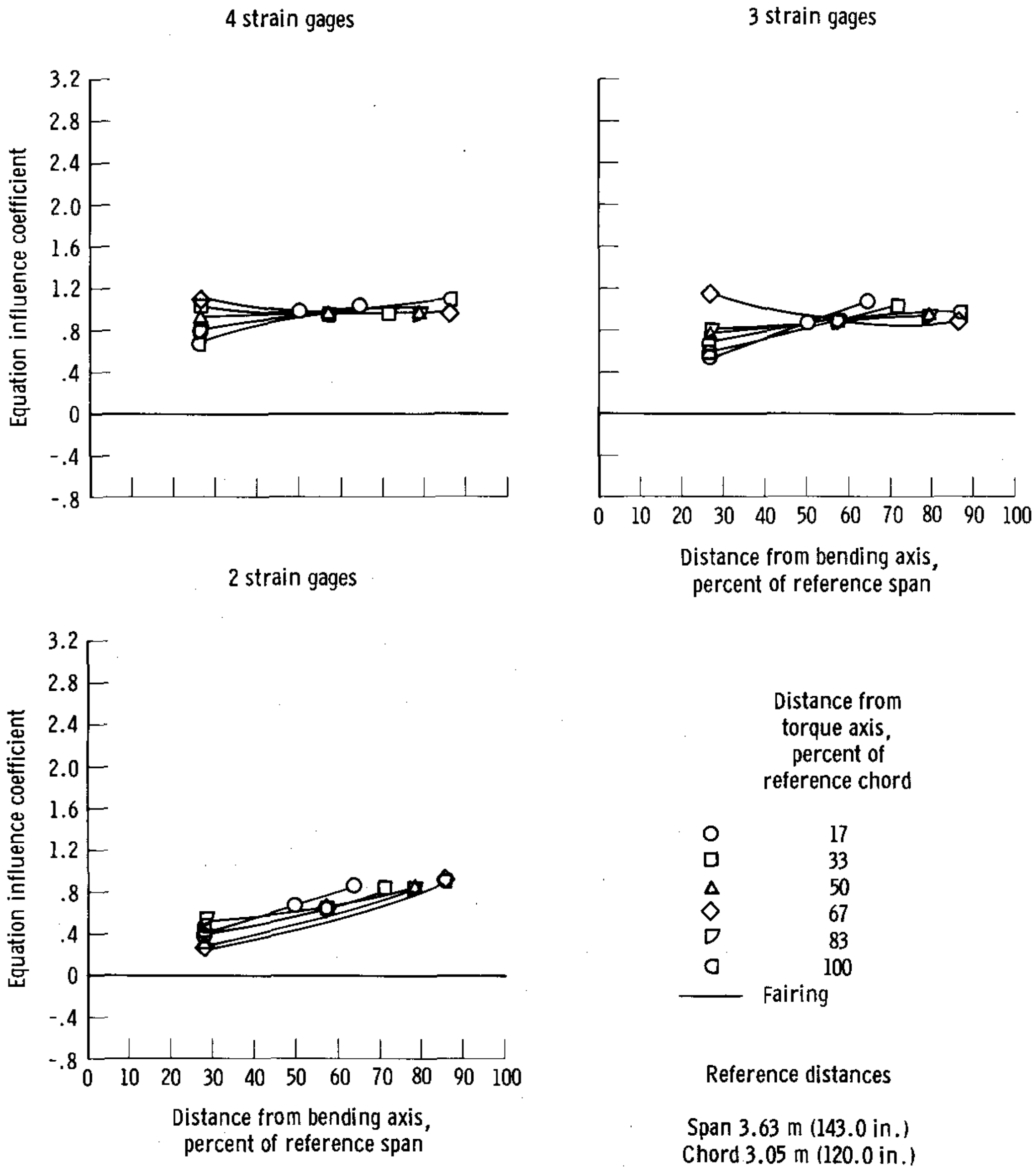
(a) Concluded.

Figure 6. Continued.



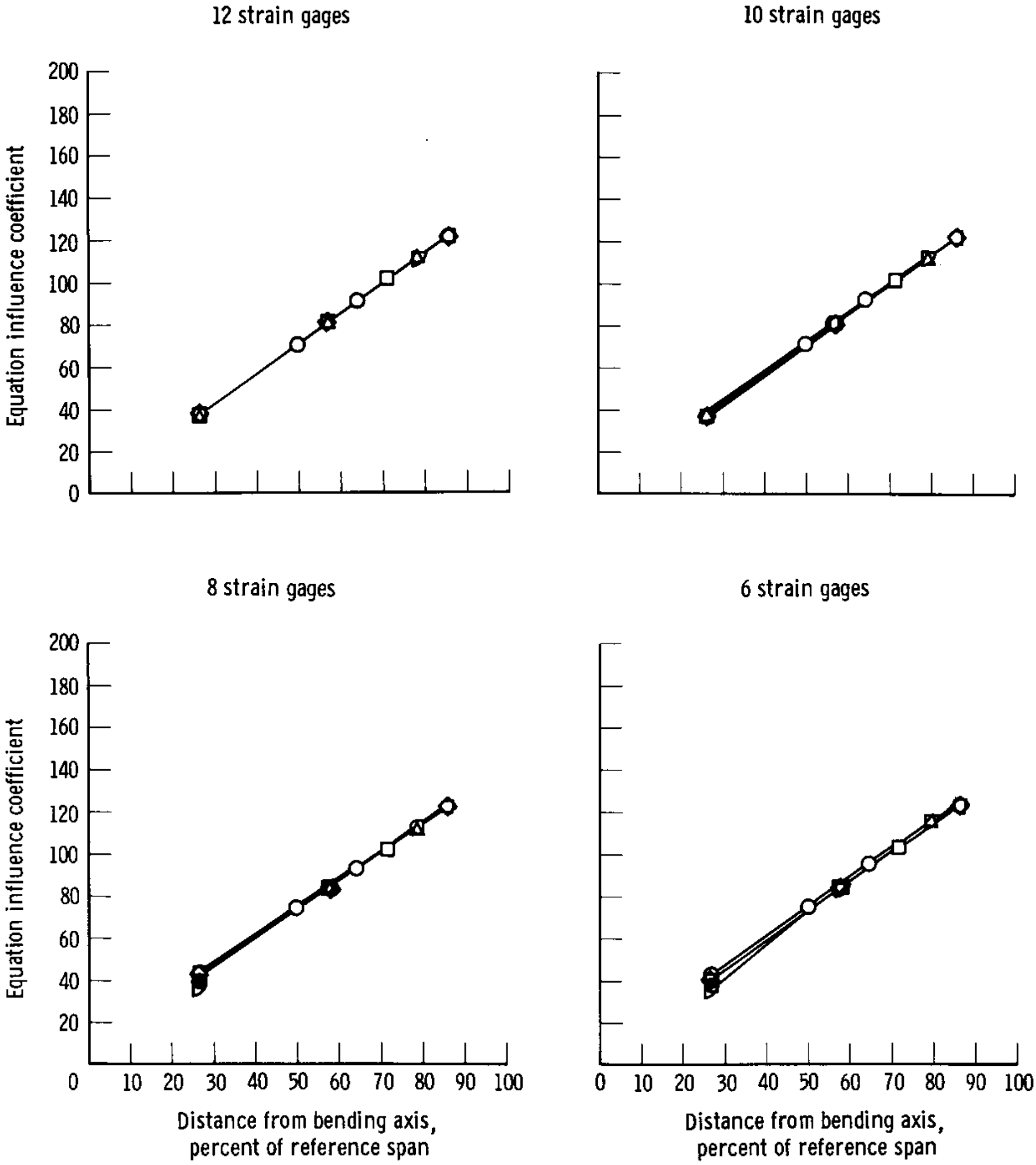
(b) *MT-value derived.*

Figure 6. Continued.



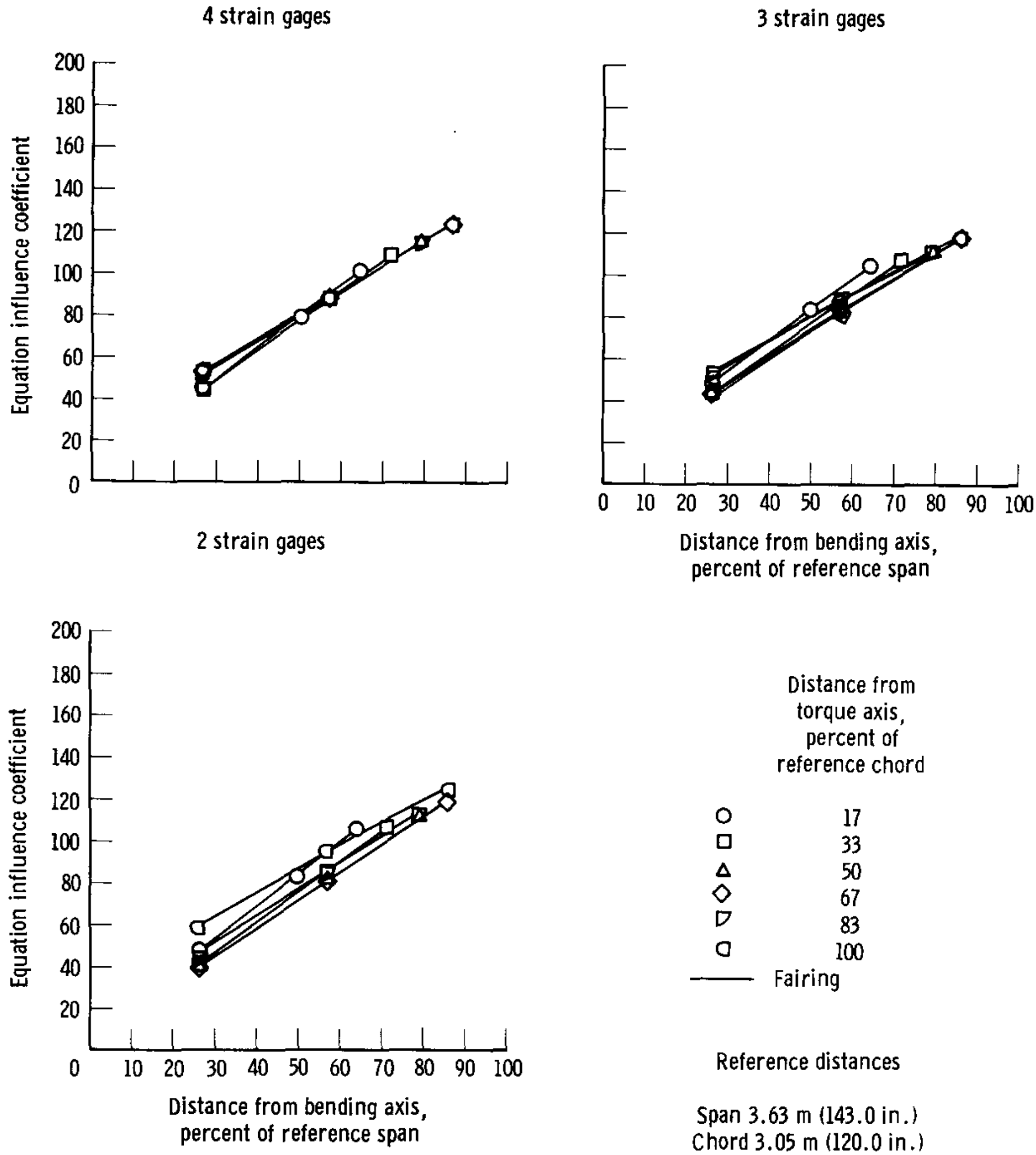
(b) Concluded.

Figure 6. Concluded.



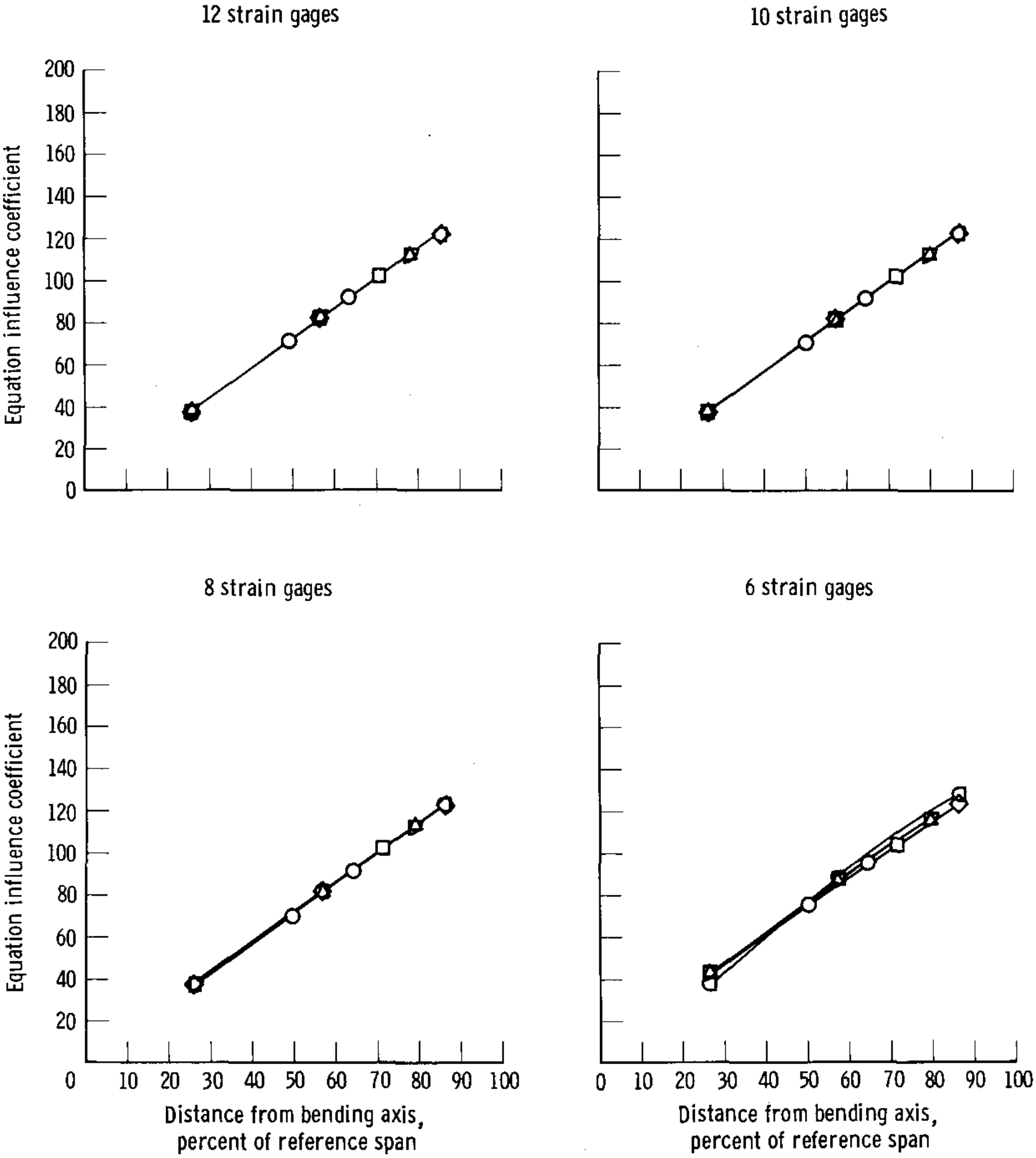
(a) T-value derived.

Figure 7. Bending moment equation influence coefficients.



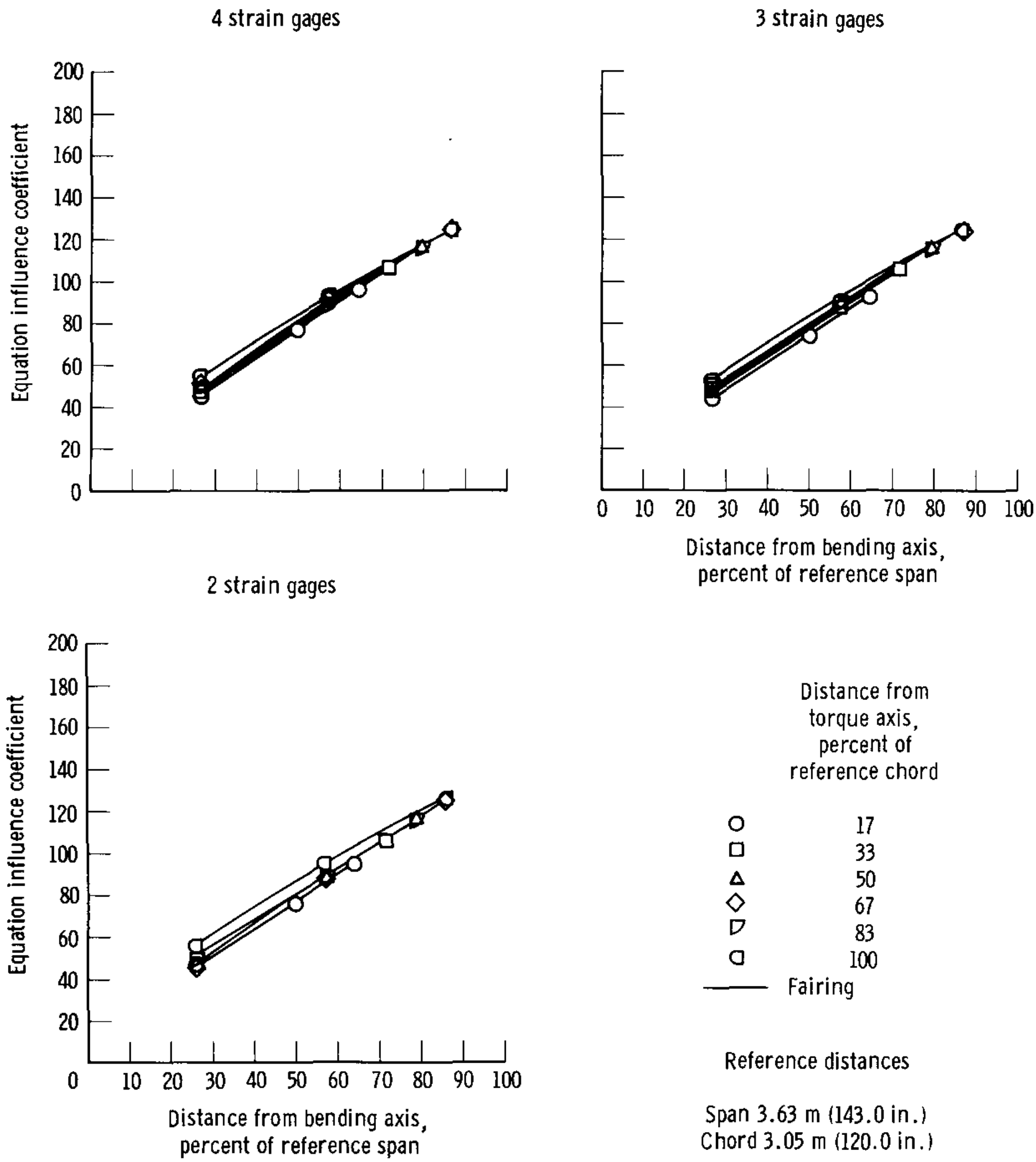
(a) Concluded.

Figure 7. Continued.



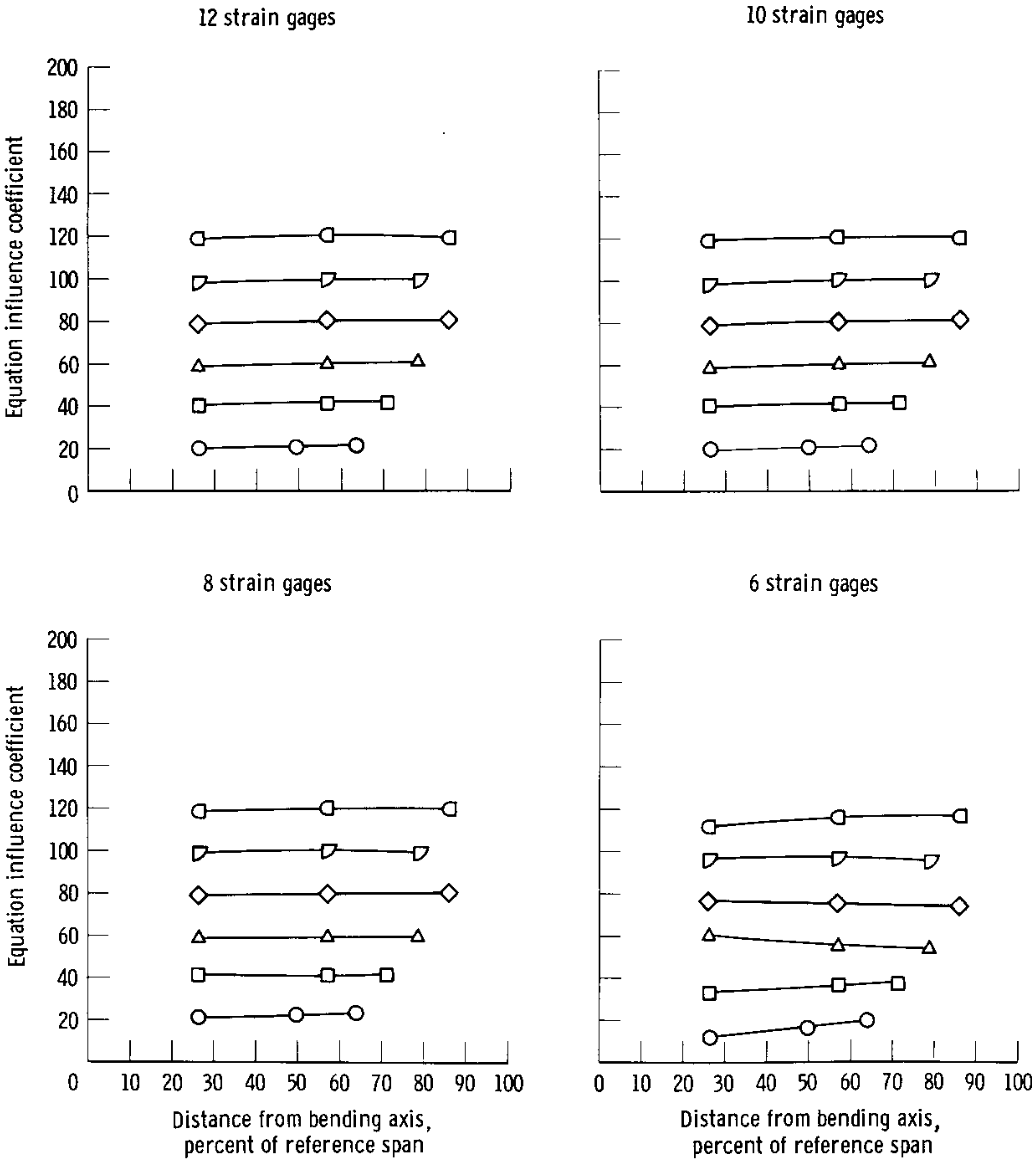
(b) MT-value derived.

Figure 7. Continued.



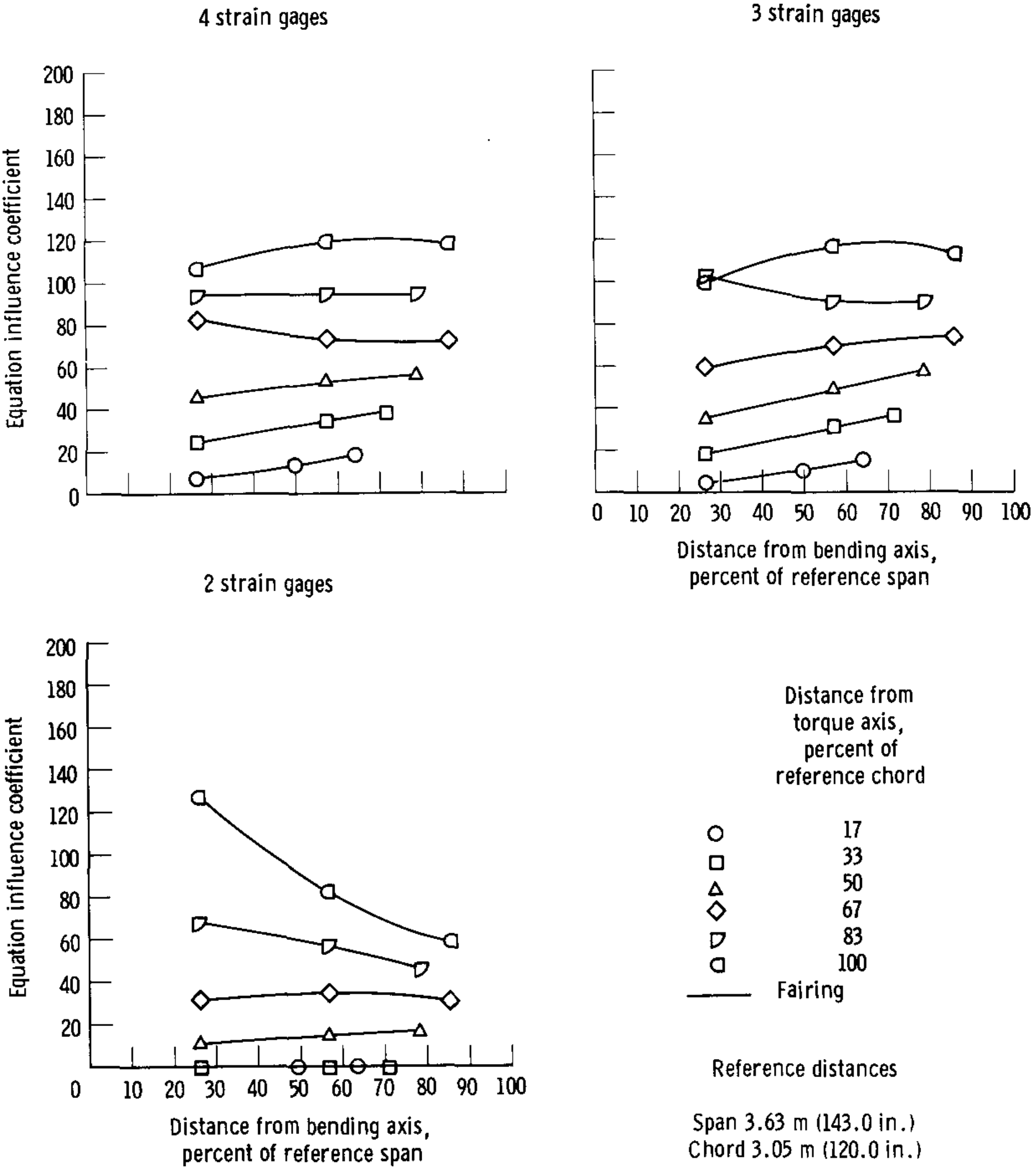
(b) Concluded.

Figure 7. Concluded.



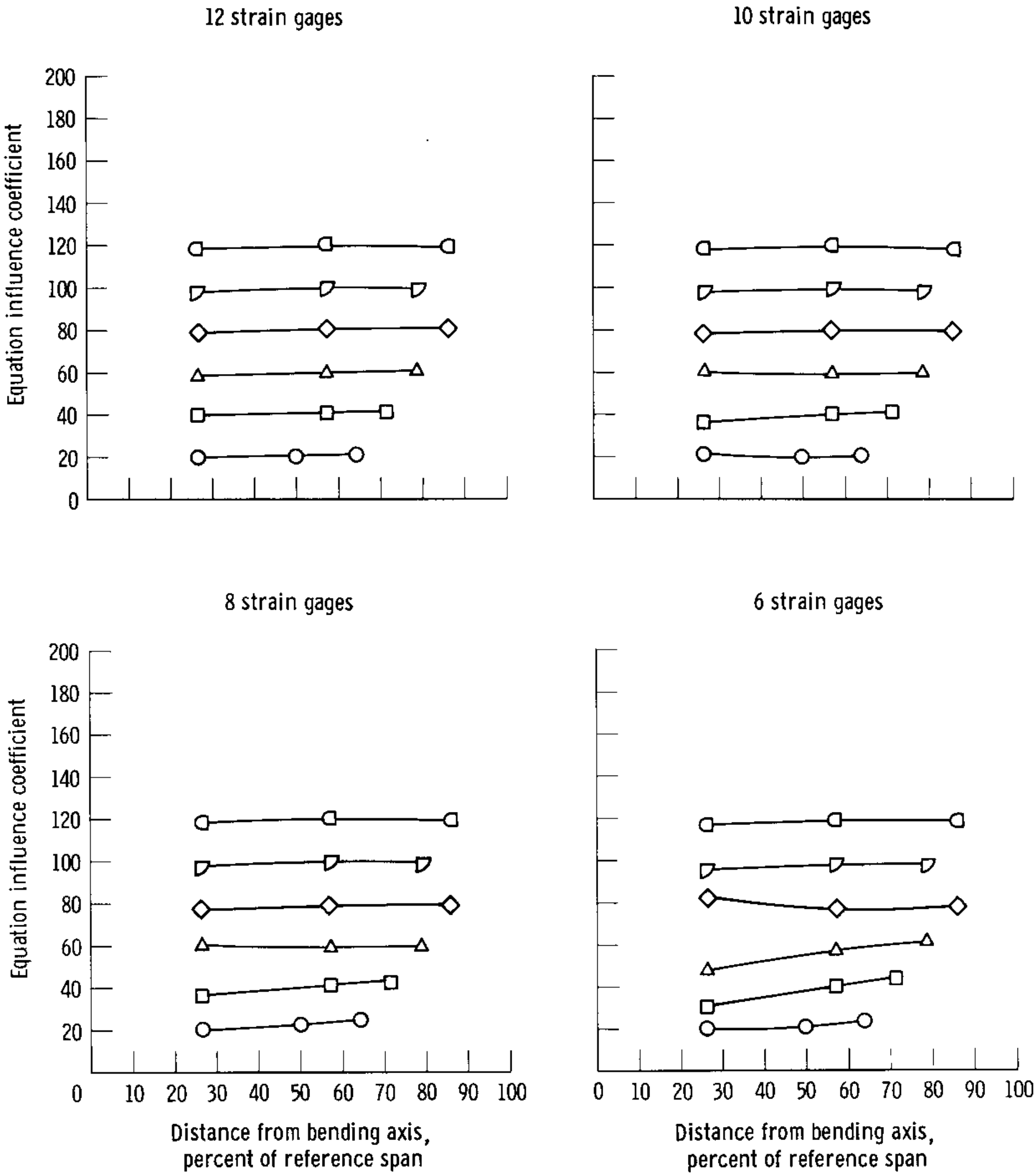
(a) T-value derived.

Figure 8. Torque equation influence coefficients.



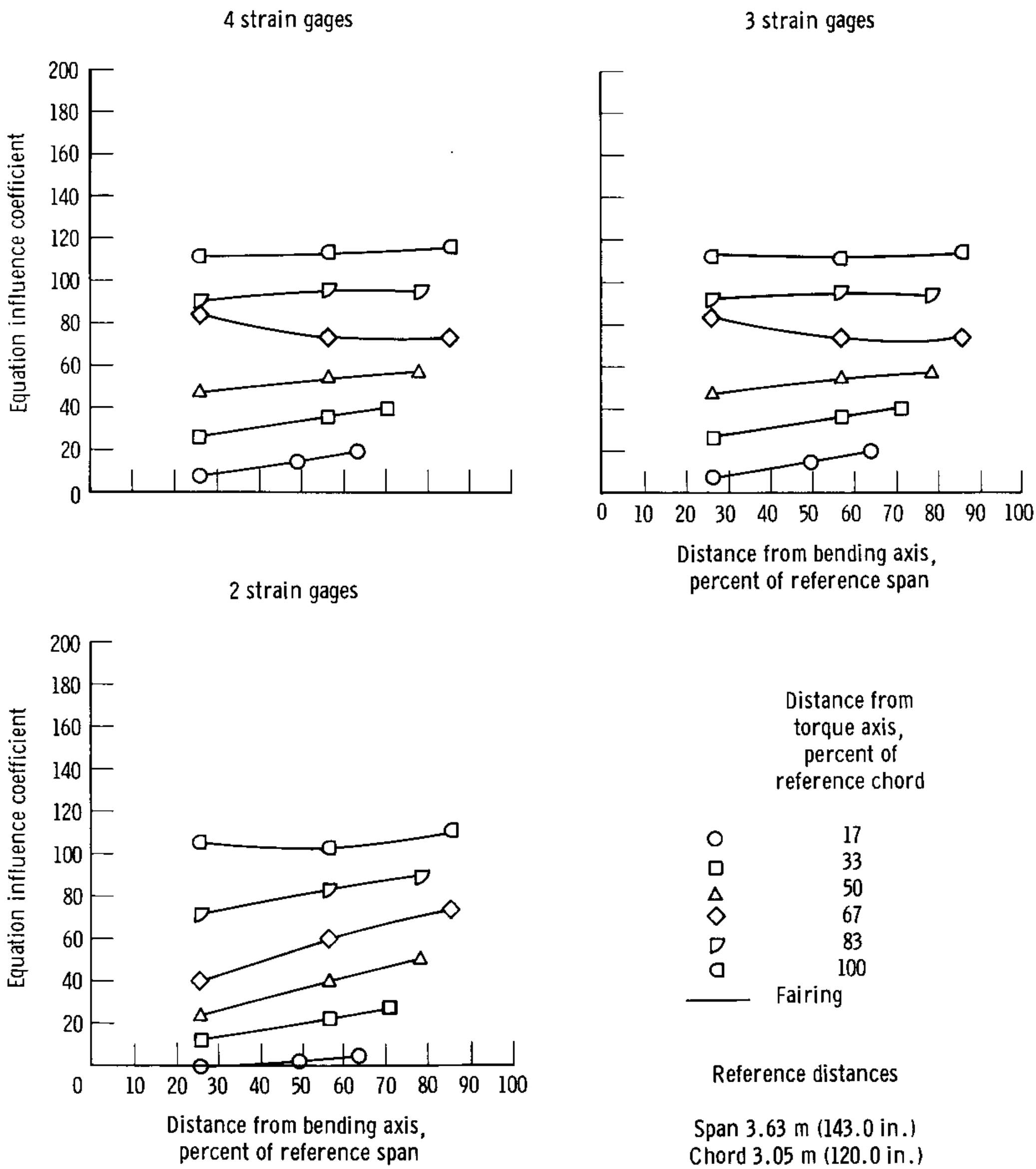
(a) Concluded.

Figure 8. Continued.



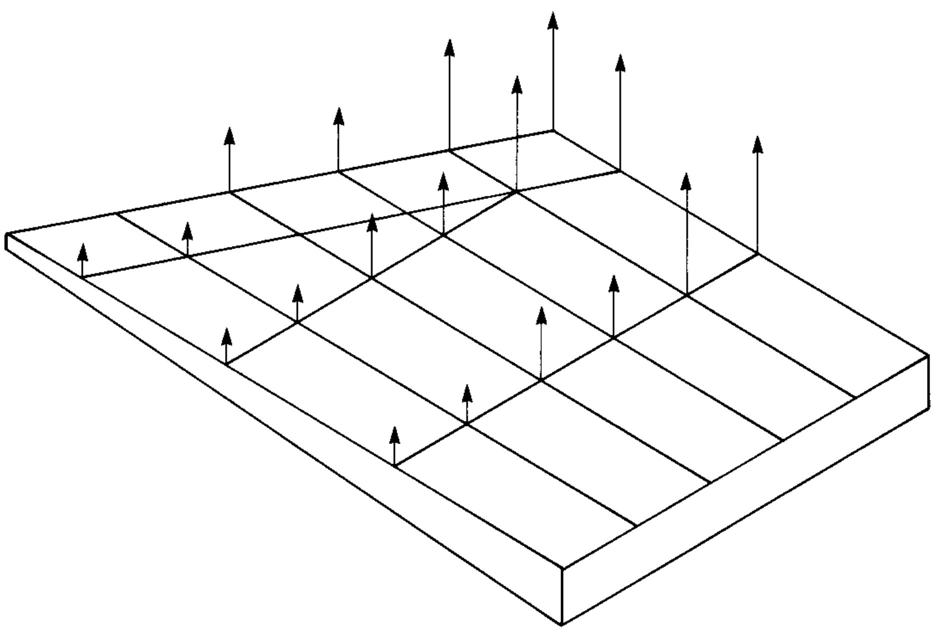
(b) MT-value derived.

Figure 8. Continued.



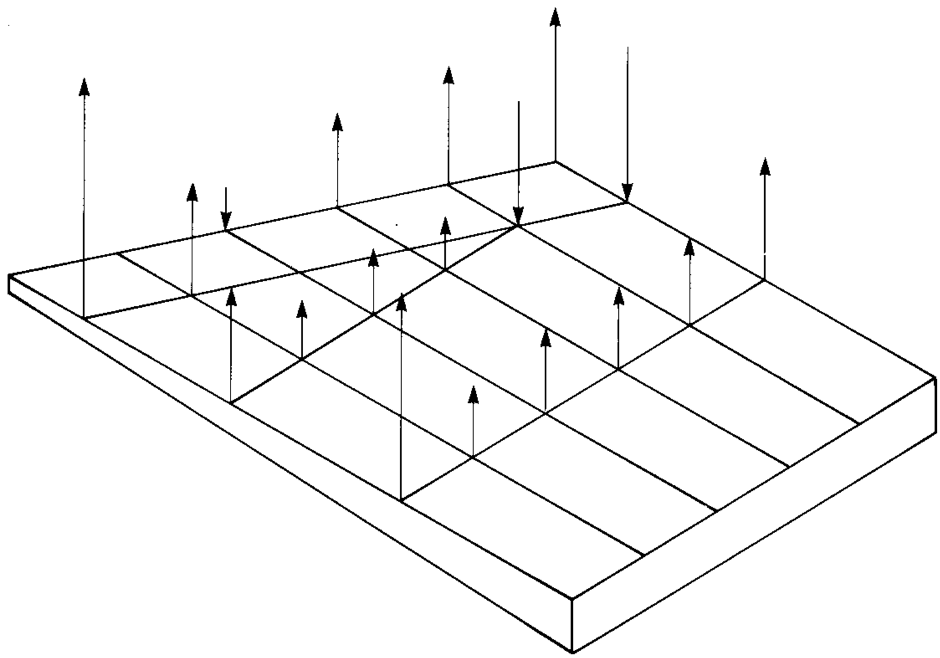
(b) Concluded.

Figure 8. Concluded.

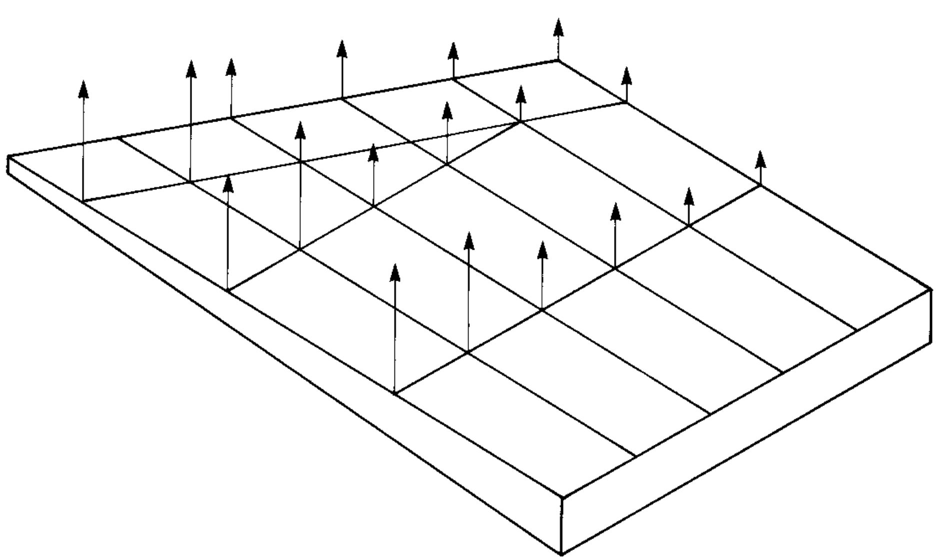


(a) Loads with forward center of pressure.

Figure 9. Shear loads applied to compute performance of load equations.

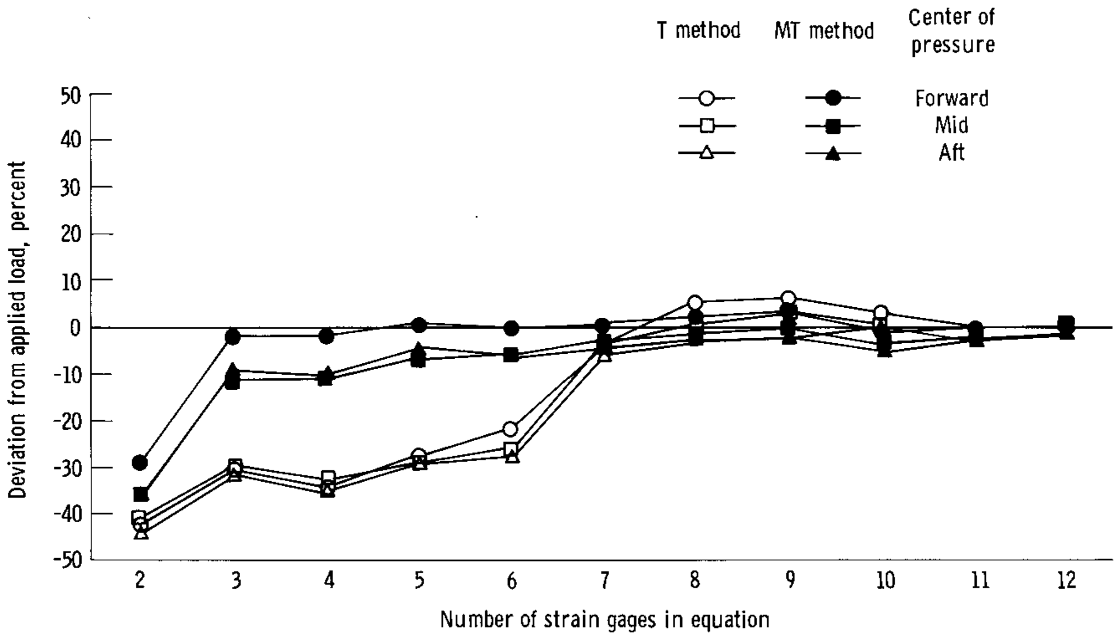


(b) Loads with mid center of pressure.

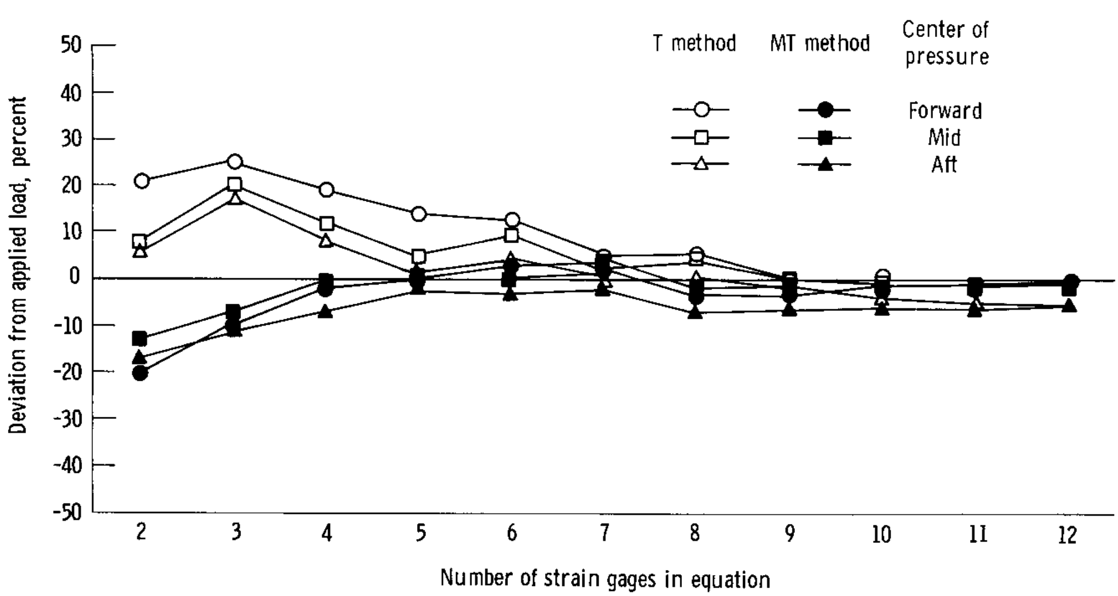


(c) Loads with aft center of pressure.

Figure 9. Concluded.

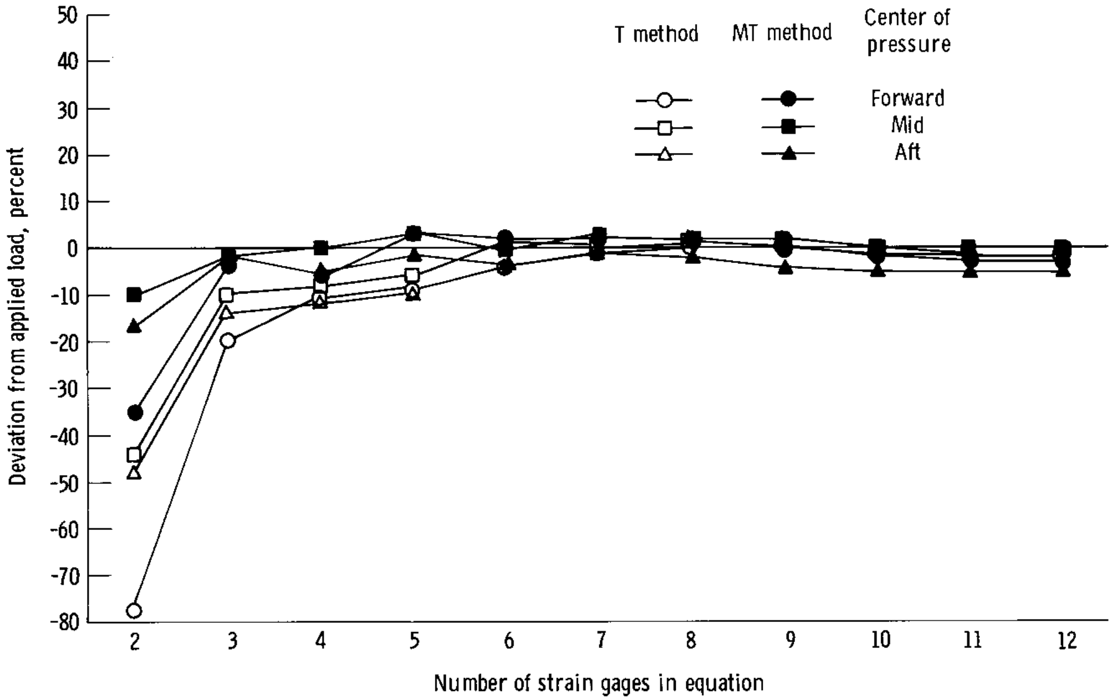


(a) Shear.



(b) Bending moment.

Figure 10. Comparison of loads computed with T and MT methods.



(c) Torque.

Figure 10. Concluded.

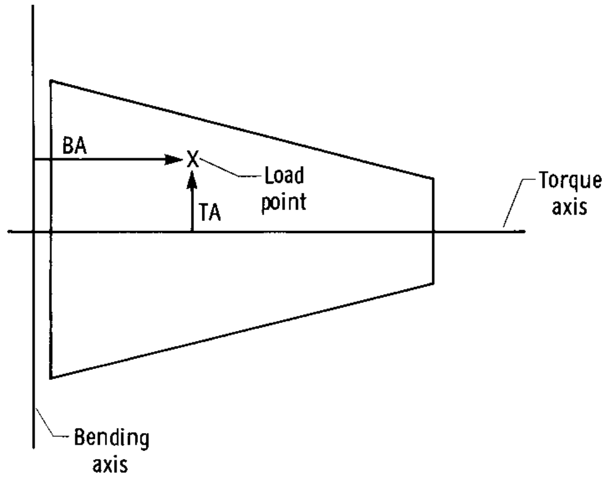


Figure 11. Nomenclature for the calibration of a lifting or stabilizing surface.

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15. Supplementary Notes

Appendix by Donald C. Black, Dryden Flight Research Center.

16. Abstract

This paper describes a technique which may be useful for selecting strain gages for use in load equations. The technique is an adaptation of the previously used T-value method and is applied in this paper to a multispar structure. The technique, called the modified T-value method, is used to reduce the number of strain gages used in a load equation from 12 to two. A parallel reduction is made using the previously developed T-value method. The two methods are compared by calculating relative equation accuracies from three applied load distributions. The equations developed from the modified T-value method proved to be accurate more consistently than the T-value method.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Flight loads Strain gage measurement	Unclassified-Unlimited Subject category: 05

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